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LEARNING RESISTANCE TO PAIN AND FEAR: EFFECTS OF OVERLEARNING, EXPOSURE, AND REWARDED EXPOSURE IN CONTEXT [1]

NEAL E. MILLER

Yale University

This study grows out of theoretical applications of learning principles to mental health by Dollard and Miller (1950) and to fear in combat by Miller (1954). It is a first step toward systematic experimental investigation of the general problem of whether resistance to stressful situations, especially fear-evoking ones, can be learned. If such learning is possible, what are the laws determining its effectiveness and generality?

One common type of stress situation is that in which *S* is in conflict because he has motivations to approach and also to avoid the same goal. Examples are the person who wants to come forward and express his ideas but is restrained by stage fright or the person who wants to approach and have normal relations with the opposite sex but is restrained by fear. Similarly, a soldier may be in conflict because he is motivated both to advance to complete his mission and to retreat to escape intense fear. Severe conflicts of this kind play an important role in neurotic behavior (Dollard & Miller, 1950).

Since the approach-avoidance conflict seems to be such an important source of stress and also has been extensively analyzed theoretically and studied experimentally (Miller, 1959), it was selected for this study. Hungry albino rats were trained to approach the goal end of an alley to receive food. Then they were placed into conflict by receiving painful electric shocks at the goal. We investigated different ways of training the rats to persist in going to the goal in spite of the fear aroused by the painful shocks.

[1] The author was responsible for the ideas, design, and write-up. James A. Faust performed Exp. I; Nariyuki Agarie and Libby Michel, supervised by Arlo K. Myers, performed Exp. II; Russell Tousley and Hanna Weston, supervised by Gordon Bower, performed Exp. III. This work was supported by a research grant, M647, from the National Institute of Mental Health of the National Institutes of Health, Public Health Service, Department of Health, Education, and Welfare, Bethesda, Maryland. We thank the Harkness Bursary Fund of Yale University for the support of Faust and Tousley.

Experiment I

The first experiment compared the effect on ultimate performance of gradual habituation to increasingly strong electric shocks at the goal with that of the sudden introduction of shock at full strength. A subsidiary purpose was to investigate a problem posed by Miller (1959, p. 225), namely, whether the first noticeable effects of weak electric shocks at the goal will be a reduction in the speed of running as would be expected from simple algebraic summation of approach and avoidance throughout the range, or whether there will be an initial period of dynamogenic effect which facilitates running.

Returning to the main problem, two factors should cause the gradual introduction to shock to help the animals to learn to resist its disruptive effects, while another factor might work in the opposite direction: (*a*) During the weaker shocks *S* will be rewarded for continuing in spite of fear, so that increasingly strong fear will become a cue for approaching. By contrast, when the strong shock is suddenly introduced, the strong fear will change the stimulus situation drastically and produce a stimulus-generalization decrement in the strength of approach in addition to eliciting the competing response of avoidance. (*b*) If Pavlov's (1927, p. 30) observations are correct, the reward occurring after the mild shocks should suppress by counterconditioning some of the fear-evoking effects of pain, and thus help *S* to continue in the face of increasingly strong shocks. (*c*) But, during the process of habituation to increasingly strong shocks, *S*s will receive a greater number of painful shocks, which may tend to make them more fearful than *S*s receiving only a single suddenly introduced strong shock. Perhaps the foregoing opposing factors are behind the two schools of thought among laymen—those who would deal with fear of water by gradual familiarization and those who would throw the victim in to sink or swim.

During the first trials of criterion testing with strong electric shock, we do not have any way of evaluating the strength of Factor *c*, the total number of shocks, relative to those it opposes. Therefore we cannot make any firm prediction. On the other hand, if the criterion tests extend over enough trials, *S*s with suddenly introduced strong shocks will have time to approach their asymptote of learning to avoid. As these *S*s approach their asymptote, the difference in total number of shocks received will become irrelevant. Since we know that learning to avoid occurs rapidly, we may tentatively assume that it occurs faster than the learning to advance to the cue of fear and the counterconditioning. On the basis of this somewhat shaky assumption, we can predict that, during the latter part of an extensive series of test trials, a group gradually habituated to increasingly strong shocks will perform better than one suddenly exposed to strong shocks.

Method

Subjects.—The *S*s were 28 male Sprague-Dawley rats approximately 90 days old at the outset.

Apparatus.—An enclosed alley 8 ft. long, 3½ in. wide, and 5½ in. high was painted flat white inside and had a hinged transparent top. Its floor was a grid of stainless steel bars $\frac{1}{16}$ in. in diameter spaced ½ in. apart, supported by strips of wood which had been boiled in paraffin.

The first 7 in. of the alley was a startbox which opened by means of a guillotine door released by a catch, pulled down by a spring,

and activating a microswitch which started an electric timer. The goal was a wet pellet of Purina mash about the size of a pea placed on an insulated aluminum plate at the end of the alley, and illuminated from above by a 6-w. bulb which was the sole source of light in the alley. When the animal touched the moist pellet, a subthreshold current operated an electronic relay which stopped the electric timer, and, on appropriate trials, turned on the shock.

The electric shock was administered to the animal's feet via the grid floor. The output of a radio transformer was regulated by a 25,000 ohm potentiometer used as a voltage divider. The output of this voltage divider was applied to the grid with a 250,000 ohm resistor in series with the rat. The output of the voltage divider was calibrated with an ac voltmeter and the duration of shock was controlled at 0.1 sec. by an electronic timer.

The rats in this experiment wore a rubber-band harness connected by a snap on the end of a T bar to a cord running along the top of the alley, going around two pulleys at either end of the alley, and back outside to form an endless loop. One of these large pulleys contained a smaller reducing one which operated a recording pen on a polygraph. The setup was like that described by Brown (1948). Since no graphic records were made in this experiment, this part of the apparatus is relevant only as part of the stimulus situation for the rat.

Feeding schedule and approach training.—The *S*s were on ad lib. water and were fed each day after the end of the experiment 10 gm. of ground Purina Lab Chow mixed with 10 gm. of water. After two days on this feeding schedule they were given three training trials, at the rate of one per day, without the starting door or harness. Then the starting door was introduced and the number of trials increased so that by Day 7, which began with Trial 11, the *S*s were running five trials a day. These trials were quasidistributed by completing a given trial on all *S*s before starting the first *S* on its next trial. On Trial 16 the harness was introduced. By approximately 50 trials, the *S*s seemed to reach their asymptote of speed, but they were continued on for a total of 75 approach-training trials.

Habituation to electric shock.—After *S*s had clearly reached their asymptote, they were divided into two groups of 14, matched on the basis of average speed on the last 10 trials and randomly assigned as the Sudden and the Gradual groups which were given the following treatments during Trials 76–150: (*a*) The Sudden group continued the rewarded nonshock training of five trials a day. (*b*) The Gradual group began with a shock of 125 v. for the first day and had the level of shock increased in 15% steps. On the first day there was no noticeable effect during the five trials. On the second day with a shock of 144 v., the first flinching reactions were observed. This level was continued for five days to determine the effect of low-level punishment. From then on the daily voltages of shock were 166, 191, 220, 253, 253, 291, 335, 335, 335. If *S* failed to reach the goal and eat within 3 min., he was removed from the alley but started on subsequent trials as usual.

Test for resistance to electric shock.—After the Gradual group had the foregoing 15 days of habituation to increasing shock and the Sudden group merely 15 days of additional training, both groups were given 20 test trials (5 per day) with the 335-v. shock at the goal.

Results and Discussion

The results are presented in Fig. 1. The part to the left of the dotted line presents the average speed (for daily groups of five trials) on the last three nonshock training days and on all of the days when the Gradual group received habituation training. The part to the right of the dotted line presents the average speed for each of the individual test trials during which both groups received the 335-v. shock at the goal.

It can be seen that the groups were reasonably well equated during the last three days of training. The first day of five shocks at the 125-v. level produced little, if any, effect. The first noticeable effect of the shock was a slight decrement produced by the days with 144 v.[2] From then on, increasingly stronger shocks produced greater decrements until the speed of the Gradual group was reduced

[2] Scores for the last two of these four days were distorted by apparatus trouble and have been omitted. To compensate for a change in the apparatus, a correction constant of .07 has been added to the average scores of both groups on all trials before these days.

FIG. 1. Effect on speed of approach of gradual vs. sudden introduction of electric shock at the goal.

($P < .01$) approximately 30% by the 335-v. shocks.[3]

The foregoing results show no evidence of an initial dynamogenic effect of weak shocks, but rather show algebraic summation as soon as any effects appear. Through an unfortunate misunderstanding, however, the initial levels of shock were higher than had originally been planned. Thus there is some possibility that the 125-v. shock, which showed no effect, is at just the level where a dynamogenic effect (which might have showed up with weaker shocks) and the interfering effect of a stronger shock, are canceling each other out.

Looking at the right side of the figure, it can be seen that on the first test trial the *S*s in the Sudden group, not yet having experienced what is in store for them at the goal, continue to run much faster than those in the Gradual group. After one shock, their performance is reduced to approximately that of the Gradual group, and with subsequent shocks, their performance drops considerably below that of the Gradual group ($P < .001$). On the first trial of the second day the Sudden group makes

[3] All reliabilities in this paper are two-tailed and, unless otherwise indicated, based on *t* tests. When a number of trials are combined, each *S* is given the sum of speeds on these trials as a single score; when trials are compared, a difference-score is computed for each *S*. The foregoing probability is for Trials 71–75 minus Trials 146–150. The next probability is for independent groups of Trials 166–170, and the final one is for Trial 156 minus Trial 155.

a temporary partial recovery ($P < .01$) —perhaps because the overnight rest introduced new cues that had less association with shock—followed by a rapid decline without any recovery on the first trials of the third or fourth days.

To present the results in a different way, on the last day of testing the 14 *Ss* in each group received 5 trials for a total of 70 tests to a group. On only three such tests were there failures to achieve the goal within the 3-min. limit in the Gradual group, while there were 14 times as many (i.e., 43) such failures in the Sudden group.

Further differences were apparent from watching the characteristic reactions of the two groups to the shocks. The *Ss* in the Gradual group flinched and sometimes squealed but remained at the goal and continued to eat. Those in the Sudden group seemed much more disturbed, lurching violently back, running away and crouching a distance from the goal. Theoretically (Miller, 1959, p. 268) *Ss* should learn the type of response they make to the shock and the responses of the Sudden group should interfere with running more than those of the Gradual group.

The results were in accord with our theoretical expectations in that a superiority of the Gradual group emerged during the later test trials. According to our theoretical analysis, the factors favoring the Gradual group were (*a*) learning to advance to the cue of fear instead of suffering a stimulus-generalization decrement, and (*b*) counter-conditioning. According to our analysis both of these effects depended on reward in the fear-evoking training situation. It is conceivable, however, that mere exposure to a sequence of increasingly strong shocks will help *S* to adjust irrespective of whether these shocks are associated with reward or administered in the training situation. The following experiments investigate this and other possibilities.

Experiment II

The main purpose of this experiment was to determine whether exposure to a series of gradually increasing shocks would be as beneficial when given outside of the test apparatus as when given as part of the rewarded training in it. A subsidiary purpose was to get a first approximation of the function relating the length of the habituation series to its effectiveness.

Method

The general procedure was the same as that in the preceding experiment with the following exceptions:

The apparatus was an alley 60 in. long, the last 12 in. of which were grid floor. At the goal *Ss* pushed back a little transparent plastic door hinged at the top until an iron strip on it came within range of a small permanent magnet which snapped the door open, exposing a food tray containing 10 P. J. Noyes Co. pellets weighing .045 gm. each, and actuating a microswitch which stopped a clock and, on appropriate trials, triggered the electric shock. For further details see Bower and Miller (1960).

The *Ss* did not wear harnesses. The initial training consisted of 70 trials after which *Ss* were divided into four matched groups. In order to cover a wider range of values and to fit into available schedules, E_M (Michel) increased the shocks in her groups twice as fast as did E_A (Agarie). The resultant groups were:

(*a*) *Gradual in alley.*—For *Ss* run by E_A, shocks began at 50 v. and were increased 13% on each day (i.e., 5 trials), to the eventual test level of 353 v. on Day 17. For *Ss* run by E_M, the sequence started and ended at the same levels, but included only every other step of E_A's sequence, except that both the 11th and 12th values were included.

(*b*) *Gradual outside alley.*—The *Ss* run by each *E* received exactly the same sequence of shocks as their partners in the foregoing group, but all of the shocks below the test level of 353 v. were given outside of the alley approximately 30 min. after the end of the

TABLE 1

AVERAGE SPEED DURING 20 TEST TRIALS WITH 353-V. SHOCK

Previous Treatment	Experimenter A	Experimenter M
Gradual in alley	.48	.61
Faster in alley	.37	.55
Sudden in alley	.35	.53
Gradual outside alley	.33	.47

daily trials in the alley. These shocks were given in a distinctive box 10 in. × 14 in. × 10½ in. deep with aluminum sides, a grid floor and a hinged Plexiglas lid. The *S*s were put into this box for each of their five daily trials which were distributed like the trials in the alley.

(*c*) *Faster in alley.*—As with Group *a*, *S*s received shocks in the alley, but the series was shorter and increased at a faster rate. With E_A the increases were approximately 63%, generating the following sequence of voltages: 50, 82, 133, 217, 353. For E_M the sequence of voltages was 50, 133, and 353.

(*d*) *Sudden in alley.*—For both *E*s this group received a 353-v. shock in the alley on the same day that the other groups first reached this voltage level.

There were 5 rats in each group for each *E*, making a total of 40 *S*s. For each *E* trials with shock were started so that the final test level was reached on the same day by all groups and so that all groups had received the same number of trials in the alley by that day.

Results

The average speeds for the 20 test trials with a 353-v. shock at the goal are presented in Table 1. It can be seen that there is a large difference between the speeds of *S*s run by the two *E*s, but that for each *E* the rank order of the groups is exactly the same. The *S*s given the gradually increasing series of shocks in the alley were better in the test series than those given the faster series of shocks in the alley, which in turn were better than those suddenly introduced to the shock for the first time. These differences are in the same direction as those secured in Exp. I. In both cases *S*s exposed to shocks outside of the alley showed the poorest performance. There was so much variability among *S*s, however, that only the difference between *E*s (which was confounded with a difference in the weight of *S*s in the two batches of *S*s) was statistically reliable. Therefore, an additional experiment was run.

EXPERIMENT III

The purpose of Exp. III was to compare the effect of three procedures on subsequent resistance to stress in the conflict test situation. The three procedures were gradual increase of shock in the rewarded conflict-training situation, gradual increase of shock outside of the conflict situation, and sudden introduction of shock for the first time in the test situation. In addition a control was added for the effects of the number of rewarded training trials.

In the preceding experiments *S*s in the Sudden group received rewarded training trials in the alley while their partners received increasing shock and regular rewards in the alley. This procedure equated the number of training trials before the test with strong shock was introduced, but meant that the Gradual group received its first experience with shocks after fewer training trials than did the Sudden group. Since all groups had reached the asymptote of speed, any effects of this difference in the number of rewarded training trials was expected to be minor. Furthermore, any such minor effect of the fewer trials was expected to work against the Gradual Group, and hence to be in the opposite direction to our experimental results.

In the meantime, Karsh (1959) secured evidence in our laboratory

suggesting that additional training trials beyond the asymptote may decrease (rather than increase) the resistance of a rat's performance to disruption by shock. To control for this surprising possibility, the present experiment used an additional Sudden group which started to receive its test with strong shocks in the alley as soon as the habituation series was started for the two Gradual groups.

Method

The *Ss* were 32 male albino Sprague-Dawley rats, approximately 90 days old at the beginning of the experiment. They were on ad lib. water and were fed 13 gm. of Purina Lab Chow approximately 15 min. after the experimental session each day. This feeding cycle started 7 days before the experiment proper.

The apparatus was the same as in the previous experiment.

For each trial in the alley the reward was 5 P. J. Noyes pellets. First each *S* was trained to push open the door over the food cup and eat pellets by being placed directly into the goalbox until it started to eat within 15 sec. on three consecutive trials. Then *Ss* were trained to run down the alley by being given two trials each day, separated by approximately 45 min. in the home cage with water. This training was continued for a total of 42 trials. It was started by Tousley, but four of the last trials were run by Weston, who also did the testing. After this training *Ss* were assigned to four groups of 8 *Ss* each. These groups were matched for mean speed on the last 10 trials and randomly assigned to the following conditions:

(*a*) *Gradual in alley.*—The *Ss* were given a 60-v. shock of 0.1 sec. duration at the goal on both of their trials on Day 22 and given shock increased by 20 v. each day until they received a 380-v. shock on Day 38. The shock sequence was changed from a percentage increment (power series) to a constant increment (linear series) because the first part of the former series seemed to be too weak while its final steps seemed to be too large.

(*b*) *Gradual outside alley.*—The *Ss* were given exactly the same sequence of shocks outside of the alley in the distinctive box. They were taken out of the home cage and given this shock approximately 15 min. after a run in the alley and immediately returned to the home cage.

(*c*) *Early sudden in alley.*—The *Ss* received their first shock, which was a 400-v. test trial, on the same day (Day 22) that the foregoing groups received their first weak shocks.

(*d*) *Late sudden in alley.*—The *Ss* received their first shock, which was a 400-v. test trial, on the same day (Day 39) that the first two groups received their first test trial.

Throughout the part of the experiment during which shock trials were given, any *S* failing to open the food door within 60 sec. after the start was returned to the home cage, given a speed score of zero, and run as usual on all subsequent trials.

Test trials were the same as training trials, except that all groups were given a 400-v. shock at the goal. Groups *a*, *b*, and *d* had 28 such trials, distributed over 14 days, *Ss* in Group *c* had 62 trials distributed over 31 days.

Results

The results are shown in Fig. 2. It can be seen that all groups were approximately equal by the end of training. As in Exp. II, the group given gradually increasing shocks during rewarded training in the alley performs the best during the test series of strong shocks at the goal. In order to test for the statistical reliability of this superiority, the speed scores for each *S* were summed for the 25 test trials following the first shock. Since the distributions of total speed scores were not normal, the difference between each pair of groups was tested by tabulating the proportion of scores above and below the median of the combined pair. The differences between the gradual group and each of the other three were reliable ($P < .01$). The differences among the other groups did not approach statistical reliability except that the Mann-Whitney *U* test yielded a *P* of less than .02 for the difference between the speeds of the Early Sudden and the Late Sudden groups during the first 25 shocks received. This difference confirms Karsh's (1959)

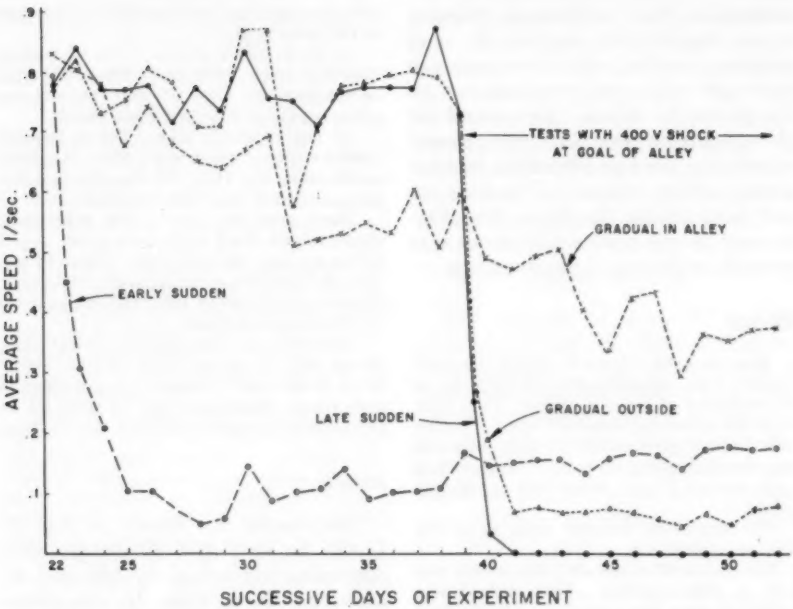

FIG. 2. How speed of approach in a conflict situation is affected by following treatments: Early Sudden group given 400-v. test shocks at goal after 21 days of approach training; Late Sudden group given similar test shocks after 38 days of approach training; Gradual in Alley group habituated to series of increasingly strong shocks at goal before test shocks; Gradual Outside group habituated to similar series of shocks in distinctive box outside of alley. Each point is average of the two trials given each day, but on the day shock is suddenly introduced producing a sharp drop, each trial is plotted separately.

suggestive results and shows that overtraining with additional rewarded trials can paradoxically *decrease* the resistance of the habit to disruption by painful electric shocks.

Finally, one unusual feature of the results should be mentioned. One of the animals in the Early Sudden group which had failed to run on 11 successive trials, gradually resumed running and by the 60th shock trial was the second fastest rat in the experiment. The fastest rat of all happened to be also in this same group in which all of the rest of the rats eventually stopped running.

DISCUSSION

The results of these experiments show that rats can be trained to resist stresses such as pain and fear. It should be profitable to study the laws governing such learning and also to study learning to resist other stresses such as frustration, fatigue, noise, nausea, and extremes of temperature. Studies of partial reinforcement are relevant, of course, to the problem of learning to resist frustration.

Parallel studies could be designed at the human level to investigate the laws governing the way people learn to resist various stresses known to be important in civilian and military activity. Human studies should investigate especially the effect of mediating, symbolic factors,

the importance of which in neurosis, psychotherapy, and problem solving I have emphasized elsewhere (Dollard & Miller, 1950; Miller, 1959).

Summary

In three experiments a total of 100 hungry rats were trained to run an alley for food reward and then given electric shocks at the goal to induce an approach-avoidance conflict. These experiments yielded the following results and conclusions:

1. During all but the first one or two trials of an extended test series with strong electric shocks at the goal, *Ss* which previously had been habituated to a gradually increasing series of shocks at the goal performed markedly better than those suddenly exposed to the test shocks for the first time. Under the conditions of these experiments we were able to teach rats considerable resistance to the stress of quite strong electric shocks at the goal.

2. A similar gradually increasing series of shocks given outside of the rewarded conflict situation produced little, if any, effect; *Ss* receiving this treatment were similar to the nonshock controls and reliably poorer than those habituated to the shocks in the rewarded training situation. Apparently, mere exposure to tough treatment will not necessarily improve resistance to stress in a different criterion situation.

3. Contrary to original expectation, additional rewarded training trials given to *Ss* which had reached the asymptote of speed reduced, rather than increased, the resistance of their running habit to disruption by shocks at the goal. Although widely advocated, mere overtraining may not always be helpful preparation for subsequent stress.

4. The results of these experiments suggest that it should be feasible and profitable to analyze further at both the animal and human level the laws governing the learning of resistance to stresses such as pain, fear, fatigue, frustration, noise, nausea, and extremes of temperature.

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CONDITIONING PERFORMANCE OF HIGH- AND LOW-ANXIOUS *Ss* IN THE ABSENCE OF A WARNING SIGNAL [1]

KENNETH W. SPENCE AND ROBERT G. WEYANT

State University of Iowa

Following the lead of Hilgard and Campbell (1936) the Iowa studies of eyelid conditioning have, except for one or two early investigations, made use of a verbal "ready" signal given from 1 to 4 sec. prior to the administration of the CS. Like Hilgard and Campbell we adopted this procedure in the belief that it had, to quote them, "the advantage of procuring greater uniformity in the organism antecedant to stimulation than is secured when no instructions are used" (p. 229). In addition, we have in most of our studies required *S* to wink voluntarily on receipt of the warning signal. This procedure also seems to have had its origin in Hilgard's laboratory. It was apparently introduced for the purpose of reducing the likelihood of a random, spontaneous blink occurring in the CS-UCS interval. Presumably, making a voluntary blink reduces the "need" to blink and hence the likelihood of a random blink. We used this procedure primarily because of our theoretical interest in the form of the conditioning curve and we found that it did greatly reduce the frequency of random eyelid closures, even to the extent that response frequency was practically zero on the first few conditioning trials.

[1] This study was carried out as part of a project concerned with the influence of motivation on performance in learning under Contract N9 onr-93802, Project NR 154–107 between the State University of Iowa and the Office of Naval Research. Acknowledgment is made to Mary Louise McClenahan who assisted in the investigation.

Presumably such a warning signal also serves to arouse anticipation of the coming noxious UCS, including anticipatory emotional reactions. According to our theory of drive in classical aversive conditioning (Spence, 1958), this anticipatory emotional response, along with perseverative emotional activity from the preceding UCSs, determine the total drive level, *D*, of *S* at the moment of occurrence of the CR. The theory further assumes with respect to *Ss* who score at the high and low ends of the Taylor Anxiety (A) Scale that this emotional activity (r_e) will be stronger and more vigorous in the case of high-scoring *Ss* than for low-scoring *Ss*. Hence the drive level (*D*) and performance level of the high-A *Ss* should be higher than that of the low-A *Ss*, a finding that has been consistently obtained in experiments in which a ready signal has been employed (Spence, 1958; Spence & Beecroft, 1954; Spence & Farber, 1954; Spence & Taylor, 1951; Taylor, 1951). Similarly, since these emotional responses (r_e) are assumed to vary with the intensity of the UCS, it would be predicted that conditioning performance will vary with the intensity of the UCS. This result has also been consistently obtained (Spence, 1958; Spence & Taylor, 1951).

The present study was designed to ascertain whether a difference in performance level in eyelid conditioning of high-A and low-A *Ss* will also be present when no warning signal is administered. Failure to obtain

such a finding would imply that the previously obtained differences were dependent upon the anticipatory effects resulting from the warning signal. However, the theory, as presently formulated, would expect the difference between the high-A and low-A *Ss* also to be present in the absence of a warning signal because of the differential perseverating effects of prior stimulations from the UCS. Different intensities of the aversive UCS were also employed so as to ascertain whether the different performance levels obtained for different UCS intensity levels were dependent upon a warning signal.

Method

Apparatus and method of recording.—The experimental rooms and equipment for recording eyelid closure and controlling the stimuli have been described in a previous study (Spence & Taylor, 1951). The CS was an increase in brightness of a 2½-in. diameter circular milk glass disc, located 51 in. in front of and slightly above the eye level of *S*, from less than .004 mL. to .23 mL. The UCS was a 50-msec. 2.0-psi air puff for half of the *Ss* and a .25-psi puff for the other half, delivered through a .062-in. diameter orifice to the right eye by a 110-v., 60-cycle ac operated solenoid valve. The tone used on nonconditioning trials was 1000 cps delivered from a Hewlett Packard Model 200 D audio oscillator through a speaker located 4½ ft. behind *S*. The intensity of this tone was not measured, but it was clearly audible. An ordinary telegraph sending key was bolted to the right arm of the chair so that when *S*'s arm rested on the chair arm, his hand was directly over the key. Although wires led off from this key, they were not actually connected to any recording device. The onsets and durations of the CS and UCS were controlled by means of Hunter-Brown (1949) decade-type electronic interval timers. The CS-UCS interval on a conditioning trial was 500 msec., while a tone trial involved the presentation for 500 msec. of the tone.

Conditioning procedure.—Each *S* was instructed to pay close attention to both the light and the tone and to press the telegraph key quickly whenever the tone sounded. They were given no instructions concerning the light and puff except that they were not to press the telegraph key when these stimuli occurred. The purpose of this discrimination response procedure was to camouflage the experiment and thus reduce the likelihood that *S* would recognize it as a study of conditioning. That our objective was achieved is revealed by the fact that only three of the 72 *Ss* recognized the experiment as involving conditioning of the eyelid to the light. This compares with our usual experience of 10% to 30% recognition, depending on the time the experiment is run during the semester.

No ready signal was used in this experiment. Intertrial intervals of 10, 15, and 20 sec., averaging 15 sec. and arranged by fixed schedule were used.

Each *S* was given 100 CS-UCS conditioning trials interspersed with 65 tone trials. The schedule was arranged so that each block of 33 trials included 20 conditioning trials and 13 tone trials. These trials were distributed so that there were never more than two successive conditioning or tone trials.

A CR was recorded whenever the record showed a deflection of 1 mm. or more in the interval 200–500 msec. following the onset of the CS. No *Ss* were eliminated on the basis of the usual latency criterion for identifying voluntary responders (Spence & Ross, 1959).

Experimental design.—The present paper presents the findings of 72 *Ss* (24 women and 48 men) who scored at the high (≥ 20) or low (≤ 9) ends of the distribution of Taylor Anxiety (A) Scale scores. Half of the *Ss* at each level of A score were conditioned with the 2-lb. puff and half with the .25-lb. puff. The proportion of women to men was constant, each of the four groups containing 12 men and 6 women.

Results and Discussion

Figure 1 presents acquisition curves for the four groups based on the percentage of anticipatory responses occurring in successive 10-trial blocks. Data are also given for the first two trials. Inspection of the curves shows that at both levels of puff intensity the high-A *Ss* performed at a higher level than the low-A *Ss*. Analysis of variance for blocks of Trials 81–100 gave an *F* value for the anxiety variable of 4.6, which is significant at better than the .05 level. The differ-

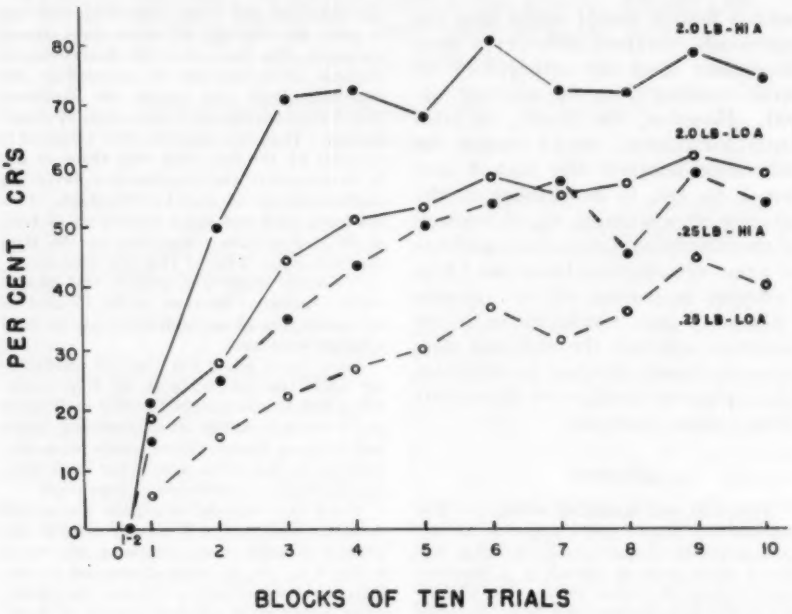

FIG. 1. Performance in eyelid conditioning as function of A-score and intensity of UCS.

ence for the puff intensity levels gave an F of 12.8, which was significant at the .01 level.

Comparison of the performance levels and differences between them for the high-A and low-A *Ss* conditioned in this experiment with the 2-lb. puff with those obtained by Spence and Taylor (1951) for the block of Trials 81–100 showed the values to be highly similar. Thus the comparable high-A and low-A *Ss* in the Spence-Taylor study gave 75.4% and 58.0%, respectively, which provides a difference of 17.4%. In the present study the values were 76.5% for the high-A group, 59.8% for the low-A *Ss*. The difference of 16.7% obtained in the absence of a warning signal is just slightly lower than that obtained in the earlier study which did employ a warning signal.

A similar comparison is available at the .25-lb. puff level. For Trials 61–80 Spence and Haggard (see Spence, 1958) obtained 51.7% and 31.5%, respectively, for high-A and low-A *Ss*, which is to be compared with the 51.5% and 33.8% for high-A and low-A *Ss* in the present experiment. The superiority of the high-A group (17.7%) when no signal was used is again only slightly lower than in the experiment in which the warning signal was employed (20.2%).

These results thus indicate there is little or no difference between the performance differential of high-A and low-A *Ss* under the conditions of a warning signal or no warning signal as used in the present experiment. In terms of the present theoretical interpretation this finding would suggest that the anticipatory emotional effects of the warning signal add little or nothing to the drive *difference* between high-A and low-A *Ss* resulting from the perseverative emotional effects of prior stimulations from the noxious UCS.

SUMMARY

Seventy-two *Ss* were given 100 conditioning trials with a visual CS interspersed with 65 trials on which only a tone was presented. Each *S* was instructed to press a telegraph key quickly whenever the tone sounded and not to press when the visual stimulus appeared. No ready signal was used on any of the trials. One-half of the *Ss* were conditioned with a 2.0-psi air puff, the other half with a .25-psi air puff. Each of these groups in turn consisted of 18 *Ss* who scored at the high end (≥ 20) and 18 *Ss* who scored at the low end (≤ 9) of the distribution of Taylor Anxiety (A) Scale scores.

The results of this study, when compared to those previously obtained with a ready signal, show that the absence of the warning signal had little or no effect on absolute level or difference in levels of conditioning performance between high-A and low-A *Ss*.

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THE EFFECT OF THE SIZE-WEIGHT ILLUSION ON ADAPTATION LEVEL

HANS G. FURTH [1]

University of Portland

This study attempts to measure the effect of the size-weight illusion on the adaptation level of comparative weight judgments. Helson (1947, 1948) used the anchor effect as a particularly striking example of what he calls the pooling of experience in the establishment of the adaptation-level (AL). A heavy anchor raises the AL, and vice versa. The method was successfully applied in both absolute (Helson, Michels, & Sturgeon, 1954) and comparative (Michels & Helson, 1949) judgments and shifts in AL were quantitatively predicted and experimentally confirmed for various conditions.

Since in the size-weight illusion a larger standard feels lighter, it may be said to function as a lighter anchor. Accordingly, it would seem worthwhile to investigate whether the AL as measured on a comparison series would be influenced by the change of size in a standard series in a way consistent with previous PSE findings and in accordance with adaptation level theory. It was hypothesized that in the present experiment a gradual decrease in the density of the standard would effect a corresponding decrease in AL for the comparison series. In order to make a comparison between two similar measures, the PSE was also computed and a high degree of correlation between AL and PSE was predicted.

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The author is now at the Catholic University of America, Washington, D. C.

METHOD

Subjects.—The *Ss* were 10 men and 10 women with no reported serious psychological or neurological disturbances. They ranged from 22 to 44 yr. of age and were presumably of better than average intelligence since all had some college training.

Material.—The comparison series consisted of five wooden blocks, 3 in. high and 2 × 2 in. at the base and top. Holes were drilled into the wood, filled with different amounts of shrapnel, and finally covered by aluminum plates nailed into the bases of the blocks. The step interval of 24 gm. was chosen to make the series comparable to other series of weights used in experiments with AL. The five blocks of this series were weighted as follows (in gm.): Co_1, 152; Co_2, 176; Co_3, 200; Co_4, 224; Co_5, 248.

For the standard series six blocks were prepared in a similar fashion. The six blocks, all weighing 200 gm., were 2 in. high, but varied in width and length, and consequently in density, as follows (the numbers in brackets refer to density): St_1, 2 sq. in., (1.017); St_2, 2¼ sq. in., (.804); St_3, 2½ sq. in., (.651); St_4, 2¾ sq. in., (.540); St_5, 3 sq. in., (.452); St_6, 3¼ sq. in., (.385).

Procedure.—Instructions were given to compare the weight of a Co block with a preceding St block according to the following scale: Very much heavier (90), much heavier (80), heavier (70), little heavier (60), equal (50), little lighter (40), lighter (30), much lighter (20), very much lighter (10). The numbers in brackets refer to the quantitative score that corresponds to a particular qualitative judgment. A small card contained the nine different ratings. As *S* was seated with his right (or dominant) side to the table and his right arm on the table, he was asked not to turn his face but to look at the card with the list of qualitative judgments which he held in his left hand. This procedure was adopted in lieu of blindfolding as a pilot study had shown that blindfolded *Ss* forgot or altered the names of the judgments, re-

TABLE 1

OBTAINED (R) AND THEORETICAL (R′) RATINGS OF EACH Co STIMULUS FOR THE SIX TRIALS

Weight of Co (Gm.)	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5		Trial 6	
	R	R′	R	R′	R	R′	R	R′	R	R′	R	R′
152	28.6	25.8	29.4	27.9	34.8	34.5	38.4	39.6	38.2	38.8	38.5	39.2
176	41.1	41.9	44.7	44.8	48.8	48.4	53.8	53.0	53.1	52.1	53.4	52.5
200	51.5	54.9	56.9	58.7	60.8	61.4	65.1	64.7	63.4	63.6	62.8	64.0
224	68.2	66.5	71.9	70.9	72.8	72.5	76.4	75.0	74.1	73.8	75.4	74.4
248	77.8	76.9	82.2	82.0	82.8	82.6	82.8	84.3	82.6	83.2	83.3	83.4

quiring that their performance be discarded.

With *S*'s elbow resting comfortably on the table, the block to be judged was placed where it was readily accessible. He was asked to lift the block once and put it down with minimal hesitation. After acquainting *S* with the range of Co weights, *E* began Trial 1 by presenting St_1 and immediately afterwards Co_3. The *S* rated Co_3 according to the proposed scale. Then he was again given St_1, and Co_2 was presented. The Co series was given in such an order that each block was judged five times, the St block being preceded in each instance by a different Co block. The order in which the Co blocks were given was as follows: 3 2 5 1 4 5 3 4 2 2 1 3 5 5 2 4 1 1 5 4 3 3 1 2 3.

St_1 was given before each of the Co, resulting in 25 ratings, five for each Co. The first rating was omitted as it was not preceded by any Co. Without interruption or explanation, Trial 2 followed wherein St_2 was substituted for St_1. Twenty-five ratings were obtained for St_2 in Trial 2, and similarly for St_3 through St_6 in Trials 3 through 6. In this way five ratings for each of the five Co with each of the six St were obtained. The final count included 100 ratings by 20 *S*s for each of the five Co under each of the six conditions.

RESULTS

The AL prevailing during the course of each trial was computed according to the least-squares solution advocated by Guilford (1954, pp. 332–333). Substituting into the equation $R = C \log S + K$, R standing for the judgment according to the rating scale and S for the weight of the Co blocks, with the average data obtained on Trial 1, one obtains: $R = 234.97 \log S - 485.72$. From the latter equation, the AL was computed by finding the value of log S which corresponds to the neutral judgment of 50, i.e., $50 = 234.97 \log AL - 485.72$. Solving for log AL, one obtains the value of 2.2830, the antilog of which gives AL = 191.9 gm. Table 1 gives the essential data for computing the AL for the six trials and shows that the Rs predicted from the equation correspond closely to the obtained Rs. Following psychological tradition Fig. 1 plots the AL and the PSE as a function of log density of standard.

The PSE was obtained by the Spearman distribution method recommended by Woodworth and Schlosberg (1954, p. 208) when the stimulus variations reach from one extreme to the other. Only three categories were used: heavier, equal, and lighter.

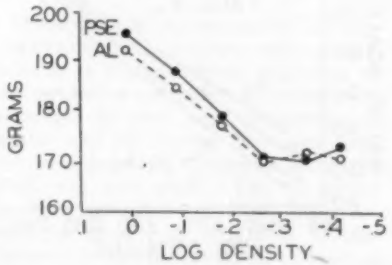

FIG. 1. Adaptation level and point of subjective equality in lifted weights as a function of log of density of standards.

The four heavier judgments were pooled into the one category of "heavier" and similarly for the lighter judgments. Two points were computed: M_+ separating the heavier from the not-heavier stimuli, and M_- separating the lighter from the not-lighter. The midpoint of these two values was taken as PSE. The formulas used were:

$$M_+ = M_s + \frac{i}{2}(\sum p_{\text{not}+} - \sum p_+)$$

and

$$M_- = M_s - \frac{i}{2}(\sum p_{\text{not}-} - \sum p_-)$$

where M_s stands for the mean of the stimulus series, i for the step interval, and p for the percentage of judgments falling in the particular category for a particular stimulus. Inspection of Fig. 1 reveals that PSE and AL are indeed closely related and follow a similar functional trend.

The Adaptation Index (AI), which is the grand mean R for one entire trial, was used for computing the significance of mean changes from one trial to another. The AI constitutes merely a rough index of the AL, a kind of grand average rating of the entire Co series in comparison to the Standard. As the AL is the point on the stimulus scale that corresponds to a rating of "medium" or "equal," an AI of 50 would correspond to an AL identical with the objective mean of the stimulus series. The AI stands in a stable inverse relationship to AL and can be readily derived for each individual. As may be inferred from Fig. 1, significant changes of AI in the expected direction occurred for the first three changes of St, but not for the last two. The t ratios of the AI changes for Trials 2, 3, and 4 were 4.42, 2.98, and 3.30, respectively. This particular finding of a limit of the illusion effect lends itself to an interesting generalization which will be discussed in the next section.

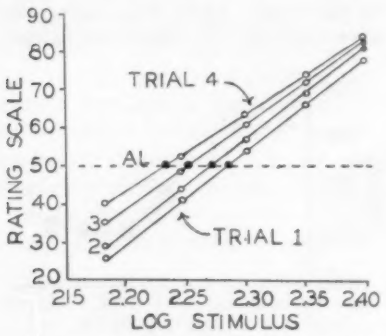

FIG. 2. Lines of best fit to the relationship between means of comparative judgments and logs of stimulus weights, for Trials 1 to 4.

Figure 2 shows the regression lines of the theoretical means of comparative judgments, as given in Table 1, plotted against log S. The last two trials were omitted since their ALs did not differ significantly from the AL of Trial 4. The shift of log AL, lying at the point where regression lines cross the axis at the height of 50, shows graphically how the change of density in standard affects the AL and its relative position within the whole series.

Finally Pearson r's computed for AL and PSE, and AL and AI, in order to express numerically the closeness of association between each pair of measures yielded values of .953 and −.958, respectively. These findings confirm the assumed closeness of these respective measures and, as far as the present experiment is concerned, validate the use of AI for computing the significance of change in AL.

DISCUSSION

The rather sudden and unpredicted limitation of the illusion requires some

explanation which could shed additional light on its nature. According to AL theory the final pooled judgment takes into account the present stimulus series, the anchor (or standard) and past experience. The relative contribution of the standard to the subjective rating depends on the discrepancy between the value of the series and of the standard. Up to a certain limit the contribution of the standard varies with the discrepancy, resulting in roughly parallel lines with comparable distances from each other on Fig. 2. But once an upper limit is reached any further change in the standard does not appreciably contribute to the pooling. It is as if the illusion effect operated within a circumscribed range and did not increase beyond it. Moreover, one would be justified in assuming that our verbal habits reflect our physiological limitations with respect to consciously spanning more than a certain range of intensities. Anchors of 100 gm. and 125 gm. might have similar subjective effects on the ratings of a comparison series of around 200 gm. Something comparable to attention span or range of cue storage might be operating here on the level of intensity. In any case, the verbal rating of "very much heavier" necessarily limits any further *expressed* increase of intensity, and probably reflects within a certain limit the lack of any subjectively *felt* increase of intensity.

The results of a conversion that would permit one to express the effect of variation of density of standard in terms of an equivalent change of weight with density held constant were as follows: equivalent weight of $St_1 = 200.2$ gm., $St_2 = 172.6$ gm., $St_3 = 149.3$ gm., and $St_4 = 126.3$ gm. This computation modified Helson's (1947) formula for weight judgments in the order St first, Co second. Solving

$$\log (AL + .25d) = \left(\frac{3 \sum \log Co_i}{N} + \log St\right) \Big/ 4$$

for log St and substituting the known values, one obtains: $\log St = 4 \log (AL + 6) - 6.8843$. This conversion allows one to say that diminishing the density of the St by nearly a half (St_4) has the equivalent effect of diminishing the weight of the St from 200 gm. to 125 gm., i.e., by $\frac{3}{4}$, and holding density constant.

As for the methodological design in this study, it may be argued that it did not attempt to compensate for the series effect, i.e., all *Ss* received the different Sts in the same order. This study was concerned with the one order that was felt might have the least dramatic effect on the AL. It can be expected that a different order of presentation will yield different values for the various ALs. To test this assumption nine *Ss* received Sts in the order 1, 6, 5, 4, 3, 2. The results are given in the following list, with the original AL in brackets: St_1, 189.2 (191.9); St_2, 175.3 (184.7); St_3, 170.0 (177.9); St_4, 168.6 (170.4); St_5, 165.2 (172.0); and St_6, 161.0 (171.3).

It may be noted that the illusion effect was present as well as the "ceiling" effect with the one difference that with St_3 the limit of the illusion was already reached. Only the critical ratios for the differences in mean AI of Trials 1 and 2 (2.42) and Trials 2 and 3 (3.37) were significant. The shift of the illusion's limit from St_4 to St_3 is undoubtedly due to the cumulative effect of St_5, St_6, and St_4 on the AL of the subsequent trials, with the result that the ALs of Trials 3 and 2 were considerably lower than in the original presentation. This particular result illustrates well the adaptation level theory according to which a change of the past AL brought by *S* to the trial (Helson's "residuals"), will alter the AL of the particular trial. Generally, it would seem interesting to investigate in a more exhaustive manner the effect of various residuals on the AL.

When the PSE is compared to the AL, it is clear that the particular value of each is liable to change slightly according to the method of computation. Moreover, although *Ss* used nine categories, all lighter and all heavier responses were thrown into single categories when the PSE was computed. The prevailing positive deviations of PSE from AL may be tentatively explained in this fashion: in the earlier trials, at least, a great number of "little heavier" and "heavier" ratings were pooled with a relatively small number of "much" and

"very much heavier" ratings; thus, the value of the heavier category was shifted towards the heavy side.

The high correlation between PSE and AL suggests that these are indeed two methods of measuring the same thing and that a valid PSE can be computed when the intensities of the stimuli are as far apart as in the present study. The main advantage of the AL over the traditional PSE seems to lie in the fact that the AL is only a particular point on a regression line which takes into account the weighted judgments over the entire range of the stimulus situation. Inspection of Fig. 2 shows that the slope of the line may be quite meaningful and that an identical AL may be found on lines of different slopes. Starting with Trial 3, there is a gradual leveling off of the slopes that contributes to the appearance of a limit to the effect of the size-weight illusion. There is an added advantage that from the formula $R = C \log S + K$ the theoretical value of any particular R or S can be obtained. The computational potential of the method is exemplified in this study where the change of density of standard was converted into an equivalent change of weight.

Finally, it would seem helpful to stress the distinction between a psychophysical method and a theory of adaptation level. The usefulness of the one does not necessarily testify to the sufficiency of the other. It is clear that computing the AL does not by itself "explain" the size-weight illusion. Yet the AL method might in fact prove useful in encompassing a variety of phenomena connected with the illusion and thus lead to a better understanding of its lawful nature.

Summary

In order to investigate the effect of the size-weight illusion on the adaptation level, ($N = 20$) *Ss* made 25 judgments on Trial 1, rating on a nine-point comparative scale the weight of a series of five blocks against a standard which was identical in size and weight to the middle block. During Trials 2–6 the procedure was repeated with different standards of constant weight but of increasing volume. The results show a steady decrease of the adaptation level to a certain point, beyond which any further diminution in density of the standard did not have a significant effect.

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REMINISCENCE IN MOTOR LEARNING AS A FUNCTION OF PREREST DISTRIBUTION OF PRACTICE

BENJAMIN H. PUBOLS, JR.

University of Miami

Reminiscence is defined by McGeoch and Irion (1952, p. 158) as ". . . an increment in the performance of a partially learned act which is attributable to rest." Operational definitions of reminiscence in motor learning have attained varying degrees of success in meeting the criteria implied by McGeoch and Irion's definition.

Several methods have been used to measure gains over rest in motor learning studies. They may be briefly summarized: (*a*) gains in the performance of a single group of *Ss* in comparisons involving a terminal prerest trial and an initial postrest trial (e.g., Bourne & Archer, 1956; Kimble, 1949a); (*b*) comparisons of postrest performance with estimates based on linear extrapolation of what performance would have been without rest (Ammons, 1947; Ellis, Montgomery, & Underwood, 1952; Grice & Reynolds, 1952; Kimble & Shatel, 1952); and (*c*) comparisons of gains of an experimental group receiving rest with those of a control group not receiving rest (Wasserman, 1951). As a definition of reminiscence, Method *a* is not adequate, because it overlooks the possibility of some improvement taking place over the rest interval merely due to the practice afforded by the last prerest trial; as such, it confounds performance increments due to rest with those due to practice.

To these may be added a fourth measure: (*d*) postrest performance of experimental groups receiving rest (e.g., Archer, 1954), or postrest performance of experimental groups minus postrest performance of control groups not receiving rest (Rockway, 1953). The Rockway method corresponds to Method *c* only if the prerest scores (means) of experimental and control groups are identical.

It is to be noted that only Methods *b* and *c* can be said to provide measures of *absolute* reminiscence, not confounded with possible practice effects. Method *a* yields a measure of *relative* reminiscence in comparisons between groups subject to different experimental conditions (Duncan, 1951), and Method *d* yields simply a measure of postrest performance.

Wasserman (1951) compared Methods *a* and *c*, finding that results may vary with the method used, and indicating the need for estimates of what performance would have been without the rest interval if one is to talk meaningfully about absolute reminiscence.

In recent years a number of studies have been devoted to assessment of the variables affecting degree of reminiscence in motor learning. As indicated above, in cases where neither the extrapolation method nor the control group method were used, absolute reminiscence (with practice effects controlled) was not being measured. The principal variables studied have been effort, amount of prerest practice, length of rest, and degree of prerest distribution of practice. The present study will be concerned only with this last variable, and a brief review of the related literature seems in order.

Apparently the first study of the effects of degree of distribution of practice on reminiscence in motor learning was Kimble's (1949b). Four groups of *Ss* practiced at the inverted alphabet printing task for 20 30-sec. trials, with intertrial rest intervals of either

0-, 5-, 10-, or 15-sec., and then received a 10-min. rest followed by Trial 21. No control groups were used which continued at their former intertrial interval between Trials 20 and 21, so the gains scores reported by Kimble are therefore measures of relative, rather than absolute, reminiscence. Gains in performance were a decreasing function of prior intertrial interval.

Archer (1954) studied the effect of distribution of practice (0-, 15-, or 30-sec. intertrial interval) on postrest performance (Method *d*) in inverted alphabet printing when a 5-min. rest came between Trials 20 and 21 for all groups. Although Archer does not report scores in terms of gains, inspection of his Fig. 1 (p. 48) indicates appreciable gains only following the massed practice condition. None of the three groups differed significantly, however, in their postrest performance scores.

Bourne and Archer (1956) assessed the effects of prerest distribution of practice on postrest performance and gains over rest using the pursuit-rotor apparatus. Five groups practiced for 21 30-sec. trials, with intertrial intervals of either 0-, 15-, 30-, 45-, or 60-sec., followed by a 5-min. rest, and additional practice. Postrest performance was an increasing function of prerest distribution of practice, and the amount of gain over the 5-min. rest was a decreasing function of prerest distribution of practice. Orthogonal polynomials analysis revealed that only the linear component of the latter function was significant.

Finally, Archer and Bourne (1956) employed prerest intertrial intervals of 0-, 30-, and 60-sec. on the inverted alphabet printing task. Twenty prerest trials were given under the appropriate intertrial interval, followed by a 5-min. rest and an additional six trials, with a 30-sec. rest interval between them for all groups. Performance on the first postrest trial did not differ significantly among the groups. Gains over rest were, as in the previous study, an inverse linear function of prerest distribution of practice.

It will be noted that in none of these studies was absolute reminiscence measured. Measures were either of gains over rest (Method *a*), postrest performance (Method *d*), or both. It should be pointed out, however, that not all of these investigators claimed to be measuring reminiscence.

The present study was designed primarily as an empirical study of the effects of degree of prerest distribution of practice on absolute reminiscence. The control group method (Method *c*) was used, such that comparisons could be made between gains of experimental *S*s receiving extended rest and control *S*s continuing at their prior intertrial rest interval.

METHOD

Subjects.—The *S*s were 100 introductory psychology students at the University of Miami. They were assigned randomly to one of 10 conditions, but with the provision that there be five of each sex in each group, to control for the sex differences in inverted alphabet printing found by Archer and Bourne (1956). They were tested in groups of 2 to 10.

Learning task.—The task was the inverted alphabet printing task. Each *S* was given a booklet measuring $3\frac{1}{2} \times 11\frac{1}{2}$ in. containing 21 printed pages, each with a 5×15 matrix of $\frac{1}{4}$-in. squares. In addition, all booklets, except those of the 0-sec. control group contained a blank page between printed pages 20 and 21, and all groups receiving other than massed practice had blank pages inserted between *every* printed page. Thus, the booklets were arranged so that a blank page would be visible during all rest intervals. The blanks further served to equate times lost during page turning for all groups. This amounted to between 2 and 4 sec.

The booklets were passed out and *S*s were instructed to number the printed pages from 1 to 21. Then the nature of the task was described and demonstrated. The *S*s were instructed to begin each new printed page in the upper right-hand corner with the inverted **A** and work from right to left. It was pointed out, to avoid possible confusion, that the letters **H I N O S X Z** appear the same inverted as upright. All *S*s were told that they would receive 21 trials, with 30 sec. per trial, or page. They were further told how much rest they would have between each trial. Finally, they were told that *E* was interested in speed and not accuracy, and therefore to work as rapidly as possible, simply printing over any errors made, and continuing.

For the first 20 trials, *S*s in the massed practice groups worked continuously, turning the page every 30 sec. upon signal. Distributed practice groups had a blank page showing during their rest intervals, and were given a 5-sec. warning before each new trial. Five of the groups (one corresponding to each length of rest interval) received a 5-

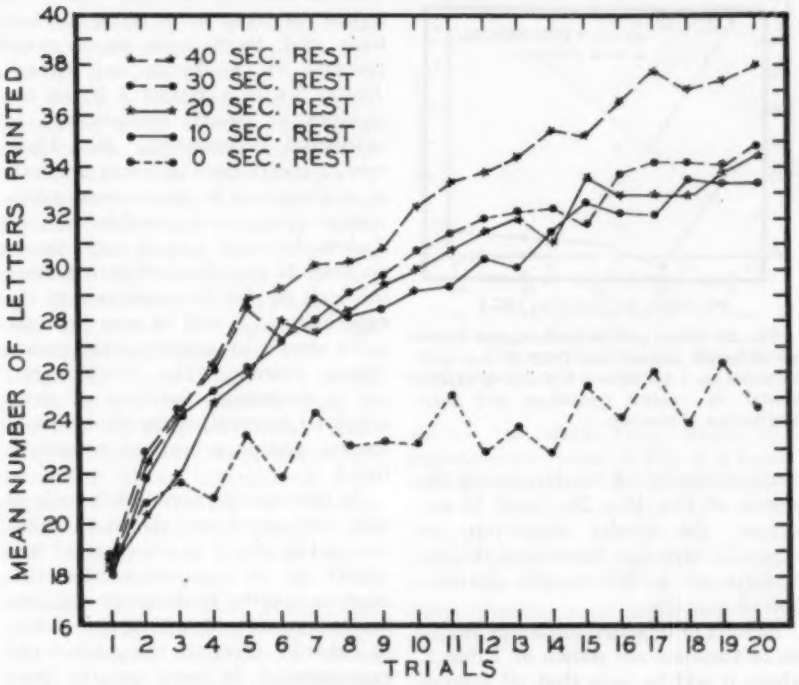

FIG. 1. Mean number of letters printed throughout the first 20 trials as a function of distribution of practice and trials.

min. rest following Trial 20; the other five groups (control groups) continued at their prior intertrial rest interval. During the 5-min. rest, *Ss* either read or talked with *E*. A single postrest trial (Trial 21) terminated the experiment.

Experimental conditions.—The experiment was set up as a 5 × 2 factorial design, with experimental and control groups practicing under one of the following five degrees of distribution of practice during the first 20 trials: 0-, 10-, 20-, 30-, or 40-sec. The interval between Trials 20 and 21 was as before for the control groups, but 5 min. for all experimental groups. This design permits a measure of absolute reminiscence by Method *c*.

RESULTS

Prerest performance.—Figure 1 plots learning over the first 20 trials as a function of distribution of practice. Corresponding experimental and control groups, which were treated identically during this phase of the experiment, have had their data combined, so that each curve is based on the scores of 20 *Ss*. Except for the

TABLE 1

ANALYSIS OF VARIANCE OF NUMBER OF LETTERS PRINTED DURING THE FIRST 20 PRACTICE TRIALS

Source	*df*	*MS*	*F*
Over-all trend	19	1612.94	328.90***
Between-group means	4	3855.37	12.41***
Between-group trends	76	47.99	9.79***
Between-*S* means	95	310.75	63.37***
Between-*S* trends	1805	4.90	

*** $P < .001$.

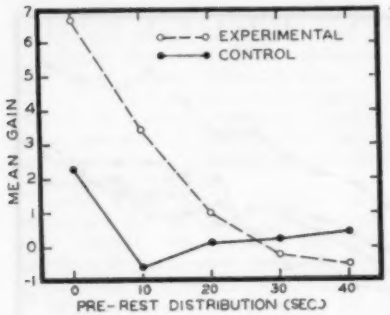

FIG. 2. Mean gain in performance (number of letters printed) on Trial 21 over performance on Trial 20 as a function of experimental vs. control conditions and prior distribution of practice.

unusual amount of overlap among the scores of the 10-, 20-, and 30-sec. groups, the results appear to be typical in revealing increasingly higher performance with increasing distribution of practice.

Results of repeated measures analysis of variance are shown in Table 1, where it will be seen that all sources of variation led to highly significant differences. The significant over-all trend indicates that, for all groups combined, improvement (learning) took place over the 20 trials. The significant between-group means indicates significant differences in performance as a function of intertrial rest interval. The significant between-group trends (Groups by Trials interaction) indicates that the rate of improvement with practice differed significantly among groups, being superior the greater the degree of distribution of practice. Regarding the significant between-individual means (individual differences), Grant (1956, p. 153) points out that this term will usually be significant when reliable performance measures are used.

Reminiscence.—Because *S*s were assigned to treatments on a random basis and there were no a priori grounds for matching any experimental *S* with a control *S*, it was not possible to assess reminiscence in individual experimental *S*s. However, a comparison of mean amounts of reminiscence in the various experimental groups was possible. Figure 2 plots the mean gain in performance on Trial 21 over Trial 20 performance for each of the 10 conditions of the experiment. It will be seen that the gains shown by experimental groups (those receiving the 5-min. rest) are a decreasing function of prior intertrial interval, while the gains of control groups reveal no consistent trend.

An orthogonal polynomials analysis was performed on the data summarized in Fig. 2 (a constant 10 was added to all raw scores for this analysis in order to eliminate negative scores), results of which are shown in Table 2. Over-all, the gains of the experimental *S*s were greater than those of control *S*s, demonstrating improvement due to rest, above and beyond any improvement attributable to practice (absolute reminiscence). The over-all effect of degree of distribution of practice was also

TABLE 2

ORTHOGONAL POLYNOMIALS ANALYSIS OF THE GAIN FROM TRIAL 20 TO TRIAL 21 IN NUMBER OF LETTERS PRINTED

Source	*df*	*MS*	*F*
Experimental vs. Control	1	64.00	5.94*
Distribution of practice	4	71.62	6.64***
Linear	1	220.50	20.46***
Quadratic	1	58.51	5.43*
Cubic	1	6.13	—
Quartic	1	1.32	—
Interaction	4	30.43	2.82*
Linear	1	112.50	10.44**
Quadratic	1	.92	—
Cubic	1	6.13	—
Quartic	1	2.16	—
Within cells	90	10.78	

* $P < .05$.
** $P < .01$.
*** $P < .001$.

significant, and the analysis reveals that the mean curve has both linear and quadratic components significant; that is, the over-all effect could be said to be a negatively accelerated, decreasing one. Finally, and most importantly, the significant interaction reveals that the amount of reminiscence varies with the degree of distribution of practice, being greater the shorter the prior rest interval. This is reflected in the fact that the two curves of Fig. 2 converge. Only the linear component of the interaction was significant.

This significant linear component of the interaction implies that, at least over the range of values investigated in this study, reminiscence is a decreasing linear function of prior degree of distribution of practice. Reminiscence apparently reaches zero with intertrial rest intervals somewhere between 20 and 30 sec. Presumably, if additional groups had been run at intertrial intervals greater than 40 sec., reminiscence scores would have remained in the neighborhood of zero.

Absolute reminiscence as a function of prior degree of distribution of practice is shown in Fig. 3, which also serves to reveal the nature of the interaction in the above analysis. This curve was obtained simply by subtracting control means from corresponding experimental means in Fig. 2. Because only the linear component of the interaction was significant, a straight line has been fitted to the data points by the method of least squares, and is also shown in Fig. 3. The equation for this line is $Y' = 4.6 - .15X$.

Relative reminiscence.—Statistical analysis of the gains of the experimental groups only provides an assessment of *relative* reminiscence effects. Orthogonal polynomials analysis of the data upon which the experimental curve of Fig. 2 is based reveals that only the linear component of trend is significant ($F = 32.21$, $P < .001$, for 1 and 45 df). Thus, both absolute and relative reminiscence are found to be decreasing linear functions of prior degree of distribution of practice.

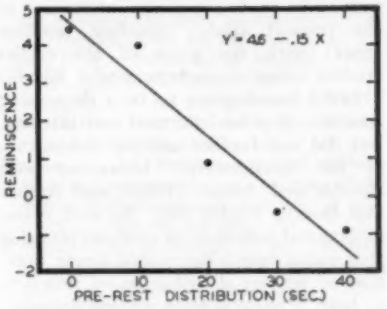

FIG. 3. Reminiscence as a function of prior degree of distribution of practice. The straight line was fitted to the data points by the method of least squares.

DISCUSSION

The major conclusion to be drawn from this study, so far as reminiscence is concerned, is that absolute reminiscence is a decreasing linear function of the degree of prerest distribution of practice. It further seems reasonable to conclude that, at least under the conditions of this experiment, no reminiscence will be obtained following prerest intertrial intervals of 20 to 30 sec. or more.

These conclusions are based on the significant linear component of the interaction of experimental-control and distribution of practice in the analysis of gains between Trials 20 and 21. Although none of the studies of the effects of distribution of practice which were reviewed in the introduction measured absolute reminiscence, comparisons of the present results with these earlier findings are instructive. The compari-

sons to be made are of the interaction of the present study (absolute reminiscence) with the gains of the earlier studies (relative reminiscence). Kimble (1949b) found gains to be a decreasing function of prior intertrial rest interval, but did not further analyze the nature of the relationship. However, both Bourne and Archer (1956), and Archer and Bourne (1956) did. In both cases, orthogonal polynomials analysis revealed that gains were a decreasing linear function of prerest distribution of practice. In both of these studies, prerest distribution of practice intervals extended up to 60 sec., but because control groups were lacking, it is impossible to say over what range absolute reminiscence would have been found. The relation of absolute to relative reminiscence in the present study was referred to in the results. The results of both of the Bourne and Archer studies, as well as the present one, are all in agreement in revealing that reminiscence (absolute or relative) is a decreasing linear function of prerest distribution of practice.

The present experiment was not designed specifically as a test of any assertions of motor learning theory. However, certain theoretical implications may be pointed out. These pertain to Kimble's (1949a, 1949b) applications of Hull's (1943) theory to the realm of motor learning. In this formulation, amount of reminiscence is taken as an index of the amount of reactive inhibition (I_R) built up during prerest practice. The present results then imply that the amount of I_R present at the conclusion of Trial 20 is a decreasing linear function of distribution of practice, or more generally, that I_R builds up as a decreasing linear function of distribution of practice.

It was possible also in the present study to test for the presence of conditioned inhibition (${}_SI_R$). This was done in the manner of Archer (1954), by analysis of the Trial 21 performance of the experimental groups. Under the assumption that a 5-min. rest interval is sufficient for the dissipation of all I_R, a demonstration of ${}_SI_R$ would require that postrest performance of the experimental groups be an increasing function of prerest distribution of practice. A simple between-groups—within-groups analysis of variance of the experimental groups' postrest scores was conducted and the results were found to be negative ($F = 1.33$, $P > .25$, for 4 and 45 df). Thus, the present results reveal no evidence for the existence of ${}_SI_R$. This is in agreement with the findings of Archer (1954), Archer and Bourne (1956), Schucker, Stevens, and Ellis (1953), and a number of others, but opposed to the results of Kimble (1949a, 1949b), Wasserman (1951), and others, all using the inverted alphabet printing task. The status of ${}_SI_R$ in motor learning remains uncertain. But, as Bourne and Archer (1956) have pointed out, other interpretations of differences in postrest performance are possible.

Summary

This study was concerned with absolute reminiscence in the inverted alphabet printing task as a function of the degree of prerest distribution of practice. A 5×2 factorial design employed 10 *Ss* in each of 10 groups. All *Ss* were given a total of 21 30-sec. trials. The five degrees of distribution of practice between Trials 1–20 were 0-, 10-, 20-, 30-, and 40-sec. Experimental groups received a 5-min. rest between Trials 20 and 21, while control groups continued at their prior intertrial rest interval. Absolute reminiscence was defined as the difference between the gain in performance of the experimental groups and the gain of the corresponding control groups, over Trials 20–21.

The results were: (*a*) Rate of learning and level of prerest performance were an increasing function of degree of distribution of practice. (*b*) Experimental groups showed a greater gain in performance from Trial 20 to Trial 21 than did control groups. (*c*) A significant linear component of the interaction in the analysis of gains in performance from Trial 20 to Trial 21 indicated that the amount of absolute reminiscence was a decreasing linear function of prior degree of distribution of practice. (*d*) No evidence for conditioned inhibition was found.

The findings were related to those of previous studies which measured relative reminiscence as a function of prerest distribution of practice.

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ABILITIES AT DIFFERENT STAGES OF PRACTICE IN ROTARY PURSUIT PERFORMANCE [1]

EDWIN A. FLEISHMAN

Yale University

In a number of previous studies Fleishman (1957a) and Fleishman and Hempel (1954, 1955) have shown that the particular combinations of abilities contributing to performance on psychomotor tasks may change as practice on these tasks continues. It has also been shown that these changes, when they occur, are progressive and systematic through the practice period until a point later in the learning period where they become stabilized. In other words, the particular combinations of abilities contributing to individual differences later in skill learning may be very different from those contributing early in learning.[2] The implications of these studies for predicting advanced levels of proficiency in psychomotor skills as well as to questions concerning the processes involved in the learning of such skills have been discussed earlier (Ferguson, 1956; Fleishman, 1956a; Fleishman & Hempel, 1955).

Contrary to earlier findings by Reynolds (1952) that the predictability of psychomotor performance decreases as a function of practice, our studies have indicated that such a decrease does not necessarily occur. In fact, it has been demonstrated (Adams, 1953; Fleishman, 1957a) that the amount of common variance between a practiced task and external measures may *increase* as practice continues, provided appropriate external measures have been included. Reynolds' study utilized only printed test measures. Our studies have shown that while certain printed measures may achieve a high degree of prediction of early psychomotor performance, psychomotor measures are better predictors of advanced levels on other psychomotor tasks. Moreover, the variance in common between different psychomotor tasks may actually increase as a function of practice on one or both of the tasks. Thus far, our general findings have been found to hold for a visual discrimination reaction task (Fleishman & Hempel, 1955), a complex serial reaction task (Fleishman & Hempel, 1954), and various other tasks of coordinated performances (Fleishman, 1956a, 1957a).

It is the purpose of the present study to evaluate possible changes in the aptitudes measured by the Rotary Pursuit Test (Melton, 1947) as practice on this task continues. It is safe to say that this task has been more

[1] The writer is indebted to W. E. Hempel, Jr., for his assistance during the conduct of this study. This research was carried out while the writer was with the Air Force Personnel and Training Research Center, Lackland Air Force Base, San Antonio, Texas, in support of Project 7703. Permission is granted for reproduction, translation, publication, use, and disposal in whole or in part by or for the United States Government.

[2] The term ability, as used here, refers to a more general, stable trait of the individual which may facilitate performance in a variety of different tasks. The term skill is more specific—it is task oriented. Thus, flying an airplane is a skill, while manual dexterity and spatial-visualization are more general abilities. Of course, abilities themselves are often products of earlier learning. This view has been elaborated elsewhere (Gagné & Fleishman, 1959).

widely used than any other single device in research on human motor learning. Yet, little is known about the nature of the abilities sampled by this task in terms of relationships with independently defined ability measures. It would appear important to establish what abilities are involved at different stages of practice on the task, especially if one is interested in the relationships between individual differences variables on the one hand and general laws of learning on the other. Moreover, definitions of ability variables involved in the performance of laboratory tasks in terms of external reference measures of such abilities may have relevance to the kinds of generalizations we may make from one task to another. Such "anchoring" of task variables in terms of abilities measured should assist in standardization and integration of "task variables" in more functional terms.

METHOD

Subjects

The *S*s were 224 basic trainee airmen at Lackland Air Force Base. Each *S* received extended practice (see below) on the Rotary Pursuit apparatus, and in addition received a carefully selected battery of printed and apparatus reference tests. These tests were thought to sample ability factors important at some stage of performance in Rotary Pursuit learning.

Half the *S*s received the reference tests before the practice task while the other half received the practice task first. Scheduling was arranged so that the printed tests were always administered to *S*s between the psychomotor reference tests and the practice task. In the administration of the psychomotor reference tests a rotational procedure was used in which the order of occurrence of each test in the series was fixed, but different *S*s started at different points in the series.

The Practice Task

The Air Force version of the Rotary Pursuit Test (CM803B2) hereafter referred to as RP, has been described fully by Melton (1947). The *S*'s task is to keep the tip of a prod-stylus in contact with a round, silver, metal target button set flush with the surface of a black Bakelite disc which rotates clockwise at 60 rpm. The black disc is .25 in. thick and 10.88 in. in diameter. The .75-in. silver target disc has its center located 3.19 in. from the center of the Bakelite disc. The hinged stylus is springloaded so that when it is held on the turntable with the handle and the rod in a straight line, a downward force of approximately 22 gm. is exerted on the silver contact tip.

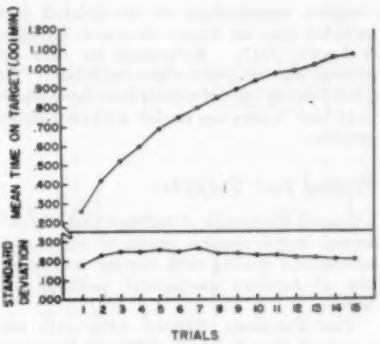

FIG. 1. Acquisition curve of performance on the Rotary Pursuit practice task.

The trials were administered with *S* in a standing position and the height of the turntable 38 in. above the floor. Four *S*s were tested at a time in a continuous session. Practice was continued through 15 trials, where each trial consisted in five 20-sec. test periods separated by 15-sec. pauses. Each of these trials (series of five 20-sec. test periods) was separated by a 30-sec. rest. Total score for a trial was the cumulated time (recorded on electric timers in .001 min.) *S* kept his stylus tip in contact with the metal target during the five 20-sec. test periods. Figure 1 presents the mean acquisition curve (and *SD*s) obtained for the 224 *S*s in the present study. It can be seen that after a slight initial increase, the group variability remains stable, with only a slight decrease in variability as practice continues. This is true even though the ceiling on performance imposed by the length of trial recorded was 1.667 min.

Brief descriptions of the printed and apparatus tests included in the study follow. Except where other references are given, more

complete descriptions of the printed tests included may be found elsewhere (Guilford & Lacey, 1947). References for each apparatus test are given where available. The reliabilities of all these tests have been shown to be high in previous studies with comparable samples.

Printed Test Variables

General Mechanics, B1902B.—Verbally presented items require practical mechanical information dealing with the use and operation of familiar mechanical methods and devices.

Tool Functions, B1904A.—For each tool presented pictorially, *S* indicates how it is properly used.

Speed of Identification, CP610A.—Pictorial items are presented in which the silhouette of an object must be identified when it is rotated and imbedded in a group of highly similar silhouettes.

Instrument Comprehension, CI616C.—For each item, which presents views of cockpit instruments, *S* must determine the proper position or orientation of an airplane.

Visual Pursuit, BM802AXI.—From a series of mazes or irregularly curved lines, the task is to trace each line visually from its beginning to its proper termination point.

Aiming (Fleishman, 1954, 1955).—Make one dot in a series of very small circles (⅛ in. in diameter) working as fast and accurately as possible. Score is the number of dots correctly placed in two 30-sec. trials.

Marking Accuracy (Fleishman, 1954).—On a standard IBM answer sheet, fill in the one alternative slot per item which is circled, going from item to item as rapidly as possible. Score is the number of items completed minus errors in two 40-sec. trials.

Apparatus Test Variables

Purdue Pegboard-Assembly[3] *(Fleishman, 1954, 1955).*—A series of small peg-washer-collar-washer assemblies must be completed as rapidly as possible. Score is the number of assembly components completed in two 60-sec. trials.

Santa Ana Dexterity, CM116A (Melton, 1947).—A series of square pegs with larger circular tops must be lifted, rotated 180°, and replaced in their respective holes as rapidly as possible. Score is the number of pegs rotated in four 35-sec. trials.

[3] Distributed by Science Research Associates, 57 W. Grand Ave., Chicago, Ill.

Rate Control, CM825A (Fleishman, 1958; Melton, 1947).—A target line moves back and forth across a curved scale, with frequent changes in direction and rate of movement and *S* attempts to keep a pointer in coincidence with a thin line by adjustive manipulations of a knob control. Score is the cumulated time on target for four 1-min. trials.

Single Dimension Pursuitmeter, CM801B6 (Fleishman, 1958; Melton, 1947).—The *S* makes compensatory in and out movements of a control wheel, in order to keep a horizontal line in a null position as it deviates from center in irregular fashion. Score is the cumulated time "on target" for four 1-min. trials.

Rate of Movement (Adams, 1953; Fleishman & Hempel, 1955).—The task is to break the beams between a series of photoelectric cells, one after another, by making a series of gross, scalloped arm-hand movements as rapidly as possible. Score is the number of such movements completed in one 2-min. trial.

Rotary Aiming (Fleishman, 1954, 1958).—The task is to strike at a series of buttons arranged in a circular pattern on a horizontal panel going from one button to the next as rapidly as possible. Score is the number of strikes in four 30-sec. trials.

Jump Visual Reaction Time (Fleishman, 1954, 1958).—The *S* must move his hand six in. to strike a button as rapidly as possible in response to a single amber light before him. A click provides him with a ready signal before each light stimulus is presented with a foreperiod (between click and light) varying in a random order from .5 to 1.5 sec. Score is the cumulated reaction time for a series of 20 reactions.

Track Tracing (Fleishman, 1954, 1958).—The *S* is required to negotiate an irregular slot pattern with a T-shaped stylus held in the slot at arms length. Score is the number of errors (contacts with the sides of the slot) during six attempts.

Complex Coordination, CM701E (Fleishman, 1958; Melton, 1947).—The *S* makes complex motor adjustments of stick and pedal controls in response to successively presented patterns of visual signals. Score is the number of completed matchings in one 8-min. test period.

Discrimination Reaction Time, CP611D2 (Fleishman, 1958; Melton, 1947).—The *S* manipulates one of four toggle switches as quickly as possible in response to a series of visual stimulus patterns differing from one another with respect to the spatial arrangement of their component parts (e.g., position of a lighted red lamp relative to a lighted green

TABLE 1

INTERCORRELATIONS[a]

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1 Trial 1, RP																									
2 Trial 3, RP	82																								
3 Trial 5, RP	73	88																							
4 Trial 7, RP	72	84	90																						
5 Trial 9, RP	65	77	86	89																					
6 Trial 11, RP	65	74	83	86	88																				
7 Trial 13, RP	58	70	79	83	87	88																			
8 Trial 15, RP	54	64	74	80	82	84	85																		
9 General Mechanics	19	22	22	18	20	19	15	12																	
10 Tool Functions	19	22	18	16	17	14	13	07	71																
11 Speed of Identification	20	24	26	26	29	26	27	26	27	28															
12 Instr. Comprehension	20	22	22	20	21	25	20	23	47	42	45														
13 Visual Pursuit	30	33	25	23	23	24	22	21	23	27	32	32													
14 Aiming	27	32	34	29	32	30	27	29	12	08	22	18	11												
15 Marking Accuracy	26	33	33	31	34	35	38	34	14	05	39	19	28	31											
16 Purdue Pegboard Assembly	20	21	18	16	17	15	17	17	19	21	46	33	27	27	19										
17 Santa Ana	28	36	39	38	32	36	37	34	19	15	38	29	20	36	29	40									
18 Rate Control	25	25	19	21	18	17	12	19	16	10	08	05	19	04	12	07	12								
19 Single Dimension Pursuitmeter	23	22	18	21	20	17	18	18	07	04	16	14	11	02	13	09	16	52							
20 Rate of Movement	19	22	23	21	23	21	18	26	16	14	16	20	17	26	13	16	24	06	19						
21 Rotary Aiming	27	25	29	27	29	26	29	29	06	−01	25	13	23	23	32	27	31	13	20	32					
22 Jump Visual Reaction Time	24	24	26	24	22	19	18	25	04	−03	23	19	19	14	31	26	30	21	19	24	34				
23 Track Tracing	34	34	35	34	32	32	32	33	16	29	34	27	30	23	20	34	28	20	14	16	30	19			
24 Complex Coordination	37	36	34	35	32	31	35	39	29	33	39	47	38	19	28	34	38	21	21	20	24	28	38		
25 Discrimination Reaction Time	21	29	32	30	27	28	32	34	28	24	46	48	27	33	28	28	45	12	18	22	11	26	28	51	

[a] Correlations have been rounded from 3 places and decimal points omitted.

lamp). Score is the cumulated response time for a series of 20 stimulus settings.

RESULTS

Data analysis.—For each test the obtained distribution of raw scores were transformed to normalized distributions of standard scores (stanines), each with a range from 1 to 9, a mean of 5, and an *SD* of 2. Conversions were made so that the 9 end of the scale was always indicative of "good" performance (e.g., low reaction time, high time on target, high number of corrects). Pearson product-moment correlations between the tests and practice task trials were then obtained.

Eight stages of practice on the RP were selected for inclusion in the factor analysis together with the 17 reference tests described above. (The eight RP stages are Trials 1, 3, 5, 7, 9, 11, 13, and 15 represented in Fig. 1, where each trial consists in five 20-sec. practice periods). The intercorrelations among the 25 variables are presented in Table 1. Eleven factors were extracted from this matrix by the Thurstone Centroid Method (Thurstone, 1947). Factor extractions were continued beyond the point where any meaningful factor variance was suspected to be present. Table 2 presents the complete matrix of centroid factor loadings obtained. The distribution of residuals, after factor extraction, is symmetrical about zero and highly leptokurtic.

Orthogonal rotations of the axes defined by these factors were made using Zimmerman's Graphical Method (Zimmerman, 1946). Table 3 presents the orthogonal solution of rotated factor loadings obtained using the criteria of simple structure and positive manifold. Factors were interpreted for psychological meaningfulness from the projections of the reference tests on the rotated axes. Loadings of the stages of practice on RP on these factors were then examined.

Interpretation of factors.—The following interpretations are based on the factor loadings of the reference tests presented in Table 3. From the loadings of the first eight variables in this table, the reader can trace the importance of each factor at different stages of practice on the practice task.

Factor I is defined readily from its high loadings in the General Mechanics and Tool Functions Tests as the factor called *Mechanical Experience* in previous analyses (e.g., Fleishman & Hempel, 1954, 1955; Guilford & Lacey, 1947). It does not appear to contribute to individual differences in performance at any stage of practice on the RP task.

Factor II is not defined by any of the reference tests, but is confined only to the variables representing trials on the RP. Moreover, loadings of RP on this factor increase progressively through Trial 9, after which they remain at a relatively stable high level. The finding of a "within task" factor which increases in importance with practice, is consistent with our findings in parallel studies with other psychomotor tasks (Fleishman, 1957a; Fleishman & Hempel, 1954, 1955). For the present, this factor must be labeled RP Specific—I.

Factor III is also confined to performance on the RP. In contrast to Factor II this factor *decreases* progressively in importance from relatively high initial levels to near zero as practice continues. For the present we will refer to this factor as RP Specific—II.

Factor IV is identified primarily by the Rotary Aiming, Rate of Movement, and Jump Visual Reaction Time Tests. These tests are reference tests of a factor consistently identified as Speed of Arm Movement (Fleishman, 1954, 1957a, 1958; Fleishman & Hempel, 1954, 1955), defined simply as the speed with which an individual can make a gross arm movement. The other tests which load on this factor all emphasize simple rapid arm movements. The present study indicates that this factor contributes to individual differences in RP performance only at a very low to negligible level throughout practice on RP.

Factor V is identified from the loadings of the Discrimination Reaction Time, Instrument Comprehension and Complex Coordination Tests which have consistently been found saturated with a Spatial Orientation factor (Fleishman, 1954, 1957b; Fleishman & Hempel, 1954, 1956; French, 1951; Guilford & Lacey, 1947; Michael, Guilford, Fruchter, & Zimmerman, 1957). This factor seems to involve the ability to comprehend the arrangement of visual stimulus pattern, primarily with respect to *S*'s body as the frame of reference. Tests of this factor often ask "What position am I in, if the situation looks

TABLE 2

CENTROID FACTOR MATRIX[a]

	Factors											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	h^2
1 Trial 1, RP	70	33	−13	−18	−20	−18	−06	−06	−14	−02	02	75
2 Trial 3, RP	79	39	−06	−10	−21	−21	04	04	−16	−10	−04	91
3 Trial 5, RP	80	43	08	08	−19	−10	10	04	−10	02	−09	91
4 Trial 7, RP	80	48	13	10	−09	−07	03	08	−03	08	−09	93
5 Trial 9, RP	79	46	18	16	−06	08	−07	04	−01	06	04	91
6 Trial 11, RP	77	46	20	17	−01	04	−07	−06	−02	−07	05	89
7 Trial 13, RP	76	42	22	24	07	07	−17	−02	08	−07	−02	91
8 Trial 15, RP	75	38	16	25	14	09	−08	−16	07	05	−08	85
9 General Mechanics	42	−32	38	−38	−18	29	15	13	−07	−12	04	74
10 Tool Functions	38	−33	38	−48	−28	16	−03	09	09	−03	−06	75
11 Speed of Identification	53	−38	06	10	12	−10	−13	23	02	07	17	57
12 Instrument Comprehension	49	−40	28	−14	11	−07	07	−09	−08	13	14	55
13 Visual Pursuit	45	−21	−06	−17	06	−06	−22	−04	−16	−07	−06	37
14 Aiming	42	−11	−09	27	−20	−06	14	−09	10	−22	16	42
15 Marking Accuracy	48	−10	−10	20	16	04	−09	10	−14	−26	08	43
16 Purdue Pegboard Assembly	43	−38	−12	08	−08	−16	−11	13	16	14	08	46
17 Santa Ana Finger Dexterity	56	−21	−08	23	−04	−09	16	05	15	−04	−04	48
18 Rate Control	32	11	−34	−40	28	16	13	12	19	−02	−07	57
19 Single Dimension Pursuitmeter	34	09	−32	−26	31	17	19	04	15	13	13	49
20 Rate of Movement	37	−14	−13	09	−09	18	16	−24	−05	13	03	32
21 Rotary Aiming	43	−11	−36	20	−08	21	−15	−08	−09	15	03	48
22 Jump Visual Reaction Time	40	−14	−30	15	13	07	07	05	−19	12	−14	37
23 Track Tracing	51	−14	−05	−06	−05	−10	−22	−05	18	10	−08	39
24 Complex Coordination	60	−26	05	−13	20	−16	−06	−14	02	03	−15	54
25 Discrimination Reaction Time	55	−31	15	06	25	−23	29	−13	12	−09	−07	66

[a] Loadings have been rounded from three places and decimals omitted.

TABLE 3

ROTATED FACTOR MATRIX[a]

	Factors[b]											
	I ME	II Sp I	III Sp II	IV SAM	V SO	VI CP	VII RC	VIII P	IX FD	X Ai	XI R	h^2
1 Trial 1, RP	06	15	51	19	02	52	31	13	00	16	02	73
2 Trial 3, RP	14	32	60	16	07	48	31	19	02	24	−04	93
3 Trial 5, RP	12	50	58	25	07	38	25	10	07	16	−09	92
4 Trial 7, RP	08	61	51	22	04	39	27	12	13	06	−09	95
5 Trial 9, RP	12	65	36	24	−01	41	24	12	18	10	04	91
6 Trial 11, RP	05	68	31	16	04	45	20	06	16	20	05	90
7 Trial 13, RP	08	72	22	06	08	48	12	13	24	14	−02	92
8 Trial 15, RP	−03	64	13	20	17	49	20	09	26	09	−08	87
9 General Mechanics	81	14	03	−04	15	02	06	05	−05	12	04	73
10 Tool Functions	83	−01	08	−07	06	22	03	04	08	−02	−06	76
11 Speed of Identification	25	16	−01	14	32	02	00	45	33	02	17	55
12 Instrument Comprehension	41	11	−04	14	50	25	−07	15	03	−06	14	56
13 Visual Pursuit	20	−04	−06	10	22	36	11	28	02	16	−06	35
14 Aiming	11	08	25	12	23	10	−01	−03	35	36	16	44
15 Marking Accuracy	02	23	06	11	37	23	19	−01	02	40	08	47
16 Purdue Pegboard Assembly	12	−10	07	19	25	19	00	31	43	−05	08	45
17 Santa Ana Finger Dexterity	12	13	20	18	39	09	06	13	42	17	−04	49
18 Rate Control	01	−02	01	−05	17	01	72	06	10	−01	−07	57
19 Single Dimension Pursuitmeter	03	03	−04	−10	18	02	64	−07	06	−09	13	49
20 Rate of Movement	15	05	04	40	21	09	13	00	20	13	03	31
21 Rotary Aiming	−01	00	−05	53	00	09	18	00	27	22	03	45
22 Jump Visual Reaction Time	−03	03	−01	40	28	06	20	24	11	12	−14	39
23 Track Tracing	16	01	04	11	15	42	12	15	35	−04	−08	40
24 Complex Coordination	20	09	−01	09	46	44	13	18	14	02	−15	55
25 Discrimination Reaction Time	15	17	11	−03	72	19	03	05	19	08	−07	67

[a] Loadings have been rounded from three places and decimals omitted.
[b] Factors are identified as I, Mechanical Experience; II, RP, Specific I; III, RP, Specific II; IV, Speed of Arm Movement; V, Spatial Orientation; VI, Control Precision; VII, Rate Control; VIII, Perceptual Speed; IX, Finger Dexterity; X, Aiming; XI, Residual.

like this?" (or vice versa). The important role of this factor in many types of psychomotor performances has been explored elsewhere (Fleishman, 1957b). However, this factor makes no contribution to RP performance at any stage of practice.

Factor VI is the factor which has consistently been found common to the RP and Complex Coordination Tests, as well as to a number of other psychomotor tasks, in many previous analyses (Fleishman, 1954, 1958; Fleishman & Hempel, 1954, 1956; French, 1951; Guilford & Lacey, 1947). Until recently, the factor was called Psychomotor Coordination, defined rather broadly as representing coordination of the larger muscles of the body in movements of moderate scope. More recent studies (Fleishman, 1958; Fleishman & Hempel, 1956) were aimed at getting a more precise definition of this factor. The results indicated that this more general factor of psychomotor coordination splits into two broad factors. One of these (previously called Psychomotor Coordination I and then Fine Control Sensitivity) was common to tasks requiring highly controlled, larger muscle adjustments; the other (previously called Psychomotor Coordination II and then Multiple-Limb Coordination) was restricted to tests involving simultaneous coordination of responses of several limbs. The Complex Coordination Test was shown to measure both factors, but RP measured only the former. Hence, the present factor must be regarded as Psychomotor Coordination I. Support for this comes from the loading on this factor of Track Tracing, which measures error in making such highly controlled arm movements. The name which has finally evolved, as the definition of this factor became clarified through successive studies, is Control Precision.

This factor is of special interest since it has been shown that this is the main common factor measured by RP during a standard test period (represented by the first three trials in this study). The present study confirms this, and also indicates that this factor remains important in its contribution to individual differences in performance on RP at all stages of practice, although there is some dip in the contribution in the middle of the practice period.

Factor VII is defined very clearly by the Rate Control and Single Dimension Pursuitmeter Tests, both apparatus tracking tasks. The finding that performance on such tasks may involve a relatively independent common ability confirms previous findings (Fleishman, 1958; Fleishman & Hempel,

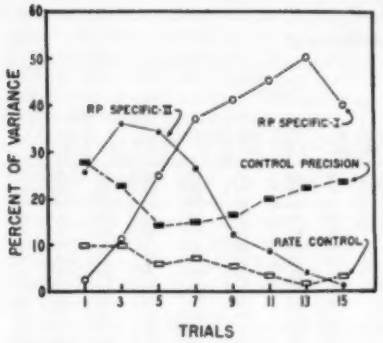

FIG. 2. Changes in the contribution of each factor to Rotary Pursuit performance as a function of practice.

1956). This factor, called *Rate Control*, appears to represent the ability to make continual anticipations and adjustments relative to changes in speed and direction of a continuously moving object. Also confirmed is the finding that this ability cuts across the traditional classification of "compensatory" versus "following" types of pursuit tasks. These results suggest that from the point of view of individual differences, this distinction of pursuit tasks may be arbitrary and the nature of these tasks may better be thought of in terms of this third underlying variable (here called Rate Control). Actually, this factor extends beyond pursuit tasks to other types of response involving rate (Fleishman, 1958; Fleishman & Hempel, 1956).

The loadings of RP on this factor are low, but the trends are highly consistent. Loadings drop progressively from .31 through Trial 3 to insignificant values late in practice.

Factor VIII is not well defined, but from the high loading of the Speed of Identification Test it appears to be the Perceptual Speed factor. Visual Pursuit, the other reference test of this factor has a loading of .28. Whatever the nature of this factor, it is clear that it does not contribute significantly to RP performance.

Factor IX is defined mainly by the two pegboard tests and is called Finger Dexterity. This ability involves facility in making rapid manipulations of small objects. Loadings of RP on this factor are generally negligible, although there is some trend for increasing loadings with practice. However, it appears, for the present, that Finger Dexterity makes no significant contribution to RP performance.

Factor X is defined by the two printed tests, Marking Accuracy and Aiming, which have defined an Aiming factor in previous studies (Fleishman, 1954; Fleishman & Hempel, 1954). This factor appears to be very narrow in score and not general to apparatus tests requiring aiming responses. RP does not load on this factor.

Factor XI is a residual factor.

DISCUSSION

The RP task is of special interest since (*a*) it is one of the most commonly used devices for the study of human motor learning, (*b*) it is a pursuit task involving continuous movements, where our previous studies have involved more discrete choice-movement tasks, (*c*) it seems to be a less complex task in terms of the number of procedural problems involved, and (*d*) the initial factorial structure indicated it to be a more "pure" task. With regard to this latter point, it was of interest to note whether a relatively "pure" task would most resist changes in factor structure as a function of practice.

Figure 2 summarizes the percentages of variance contributed by those factors found in RP at each stage of practice. The estimates of percentages of common variance were obtained by squaring the individual factor loadings. These curves show the dramatic decrease in the importance of Factor III and the corresponding increase in Factor II as practice continues. Neither of these factors were definable by the external reference ability measures. The main factor measured by RP which was defined by external measures was the Control Precision factor and this contributed roughly 25% of the variance at late as well as early stages of practice. The factor called Rate Control contributes slightly (10%) early in practice but decreases steadily in importance.

The increase in importance of a factor common only to the task, itself, agrees with our findings with other kinds of psychomotor tasks (Fleishman, 1957; Fleishman & Hempel, 1954, 1955). This is consistent with the view that skill in later performance is more a function of specific habits acquired

during practice on the task itself, relative to transfer from previous abilities, skills, and habits. While factors of *decreasing* importance have been found in other tasks, this is the first study in which such a factor was not defined by external ability measures. The nature of this decreasing factor is not immediately apparent. It is possible to speculate that this factor represents a "learning set" of some kind, which facilitates learning early but which drops out as a contributor as all *S*s gain experience with the task. Whatever explanation is adopted would have to account for the fact that we have not found this decreasing "within-task" factor in our studies with other motor tasks. We have already noted, however, that RP differs from previous tasks studied in its requirement for continuous movements, in its relative (initial) factorial "purity," and in its procedural simplicity. Whether any of these or other task characteristics are of consequence in relation to the decreasing "within-task" factor remains to be determined.

Perhaps, the most important result is the specification of the main source of variance RP performance has in common with other tasks. The Control Precision factor, which contributes at all stages of RP performance, has been found general to performance on a variety of different psychomotor devices. We may infer, then, that the main common ability sampled by RP is the ability to make highly controlled (but not overcontrolled), precise, large muscle adjustments. (Thus, the consistent "validity" of this test for predicting such complex performances as airplane piloting [Fleishman, 1956b; Melton, 1947] is "explained," even though there is little superficial resemblance between RP performance and piloting performance; both tasks tap the common ability of Control Precision.)

Another finding was the secondary contribution of a Rate Control factor early in practice, with a progressive decrease in importance of this factor through practice. This is consistent with what is observed in performing on RP, where the task seems initially to be more of a pursuit task; one has difficulty in leading the target properly and even in predicting where to move in relation to it. This difficulty seems to disappear after brief practice, where the task becomes one of minimizing erratic movements while making a smooth, continuous, circular arm movement.

A recent attempt to analyze the components of RP performance has been made by Ammons, Ammons, and Morgan (1958), using a micromation approach. They used motion picture recordings of performance, a rational classification of "types of movements," and a "scoring stencil" employed over the film frames at different stages of practice. Scores included the number and duration of circular, tapping, looping, reverse, and crisscross movements, as well as movements ahead of the target (leading) and behind the target (following). From this analysis they conclude that, "The *S* who can make the basic movement but whose timing is 'off,' is well on the way to a higher performance level, as compared with the *S* who cannot make the basic movement." This conclusion fits well with the present findings that (*a*) individual differences in Rate Control ability may facilitate early learning to a small extent, but this does not predict later learning; and (*b*) the main common factor contributing to advanced as well as early proficiency is Control Precision.

A completely different approach to the components of RP performance was made by Archer (1958). By inserting a mercury-puddle sensing device in the stylus he was able to measure the number and duration of "noncircular" movements to compare with "time-on-target" scores at different stages of practice. Archer's data show that number and duration of these "noncircular" movements decrease as practice continues. Archer does not provide a correlation between scores on this component at early stages of learning and "time-on-target" at later proficiency levels, but this would be highly relevant to our discussion. However, all three lines of investigation support the view that

ability to make the proper controlled circular movement (even though one is off in his timing, and therefore off target, during early stages of learning) facilitates high later proficiency.

A final point relates to the high degree of specificity found in RP performance compared with other psychomotor tasks. The largest amount of RP variance in common with all the other tasks, at any stage of practice, was approximately 48% (the sum of squared loadings of all factors excepting the two "within-task" factors). This agrees very closely with previous communality estimates from factor analytic studies in which only single scores of RP were included. Communality estimates in six different studies (Fleishman, 1954, 1957a, 1958; Fleishman & Hempel, 1954, 1955, 1956) were all between .45 and .50. Estimates from the numerous earlier studies which included this test as part of the Aircrew Classification Battery (reported in Guilford and Lacey, 1947) were somewhat lower (.30–.40), which is reasonable since these batteries contained few psychomotor devices. On the other hand, it has been possible to account for more common variance in the case of several other psychomotor devices: 70% for the Complex Coordination task (Fleishman, 1957a; Fleishman & Hempel, 1954); 60% for the Discrimination Reaction Time Test (Fleishman, 1947a; Fleishman & Hempel, 1955); 58% for the Plane Control device (Fleishman, 1957a); and 66% for Unidimensional Matching (Fleishman, 1957a). The relative specificity of RP performance at least raises questions about the extent to which we can generalize from RP experiments to experiments with other tasks.

Experiments of the type described here suggest the hypothesis that what is improved, in learning, is in large measure something specific to the task. This, of course, does not preclude changes in common factors, also. Furthermore, it should be stressed that a factor's increase in importance does not necessarily mean an average gain in that ability. It means that a greater portion of individual differences can be accounted for by that factor. In the present instance, although individual differences continued to be a function of the more general Control Precision ability, increasingly, differences in performance were attributable to differences arising from specific experience with the task.

Summary

Extended practice was given 224 *Ss* on the Rotary Pursuit apparatus. These same *Ss* also received a battery of 17 reference ability measures. The intercorrelations were obtained among scores at eight stages of proficiency on the practice task together with the scores on the reference measures and these were subjected to factor analysis study. The results indicate that the main common factor identifiable from the reference tests and contributing to individual differences in RP performance, is the factor previously called Control Precision. This has been defined as the ability to make highly controlled, precise muscular adjustments. This factor contributed to RP performance at early as well as late stages of practice. The Rate Control factor contributed slightly to differences in early proficiency, but its contribution decreased with practice. Two major factors were not identifiable from the reference battery. One of these increased in importance as practice continued, while the other decreased steadily in importance. The increasing "within-task" factor has been found with other psychomotor tasks and may reflect the increasing importance of individual differences in the specific habits and skills acquired on the task itself. The hypothesis was advanced that the decreasing factor may reflect some kinds of "learning sets" which facilitate early learning, but not later learning.

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EXTINCTION FOLLOWING PARTIAL AND CONTINUOUS PRIMARY AND SECONDARY REINFORCEMENT [1]

NANCY A. MYERS

University of Massachusetts

The purpose of this experiment was to evaluate and compare the effects of partial reinforcement, both primary and secondary,[2] upon an operant response of children. The bulk of experimental data reveals that there is considerable resistance to extinction after partial reinforcement procedures, with all types of situations and reinforcements. However, no study has attempted to demonstrate the effects of partial reinforcement, both primary and secondary, varied simultaneously, yet independently.

Several studies (Bijou, 1957; Fattu, Mech, & Auble, 1955; Grosslight & Child, 1947; Lewis, 1952) reported procedures of partial reinforcement with children. All found greater resistance to extinction following low percentages of reinforcement in training than following continuous or high percentages of reinforcement. Others (Siegel & Foshee, 1953; Spiker, 1956) reported extinction data for children given different numbers of conditioning trials. Spiker found no differences in number of responses after 12 and 24 conditioning trials with a lever-pulling task, reinforced by colored lights. Siegel and Foshee, however, reported a significant increase in number of children's bar-pressing responses in extinction as a functioa of increased number of prior candy reinforcements. Since the present study was concerned with partial reinforcement effects, an attempt was made to control for the varying number of reinforced trials.

Extinction in children after secondary reinforcement has been the concern of at least two studies (W. W. Lambert, E. G. Lambert, & Watson, 1953; Mitrano, 1939). Mitrano tested feebleminded children on two dispensers, one where they used a marble to get a poker chip, the other where they then used the chip to get a candy. The number of marble-insertion responses of *S*s who received no poker chips or candy in extinction was greater than the number of poker chip insertion responses made when only candy was withheld. Lambert et al. (1953) reported similar results with children when they were taught to turn a handle, get a token, insert the token, and get a candy: there was greater resistance to extinction with *no* token reinforcement. But when an additional group was required to make the same response (turning) at each block point, more resistance to extinction was found following token reinforcement. The present study also requires the same response to get the

[1] This article is based on a thesis presented in partial fulfillment of the requirements for the PhD degree, Department of Psychology, University of Wisconsin, 1957. The author wishes to thank D. A. Grant and J. L. Myers for their helpful advice.

[2] In this study a secondary reinforcement is defined as any object which through some type of association with a primary reinforcer has obtained the characteristic of increasing resistance to extinction when the primary reward is removed. Primary reinforcement is defined as any stimulus which, without previous association with another stimulus, increases the rate of behavior producing it. The terms "primary" and "secondary" reinforcement will be used throughout, although the efficacy of the candy and tokens remains to be shown as results of the experiment.

token and the candy, and should help clarify these equivocal results.

The three major variables involved in this investigation were percentage of primary (candy) reinforcement, percentage of secondary (token) reinforcement, and the presence or absence of secondary (token) reinforcement during extinction. On the basis of previous data one prediction was greater resistance to extinction for the partial-candy and partial-token groups. Principles of secondary reinforcement yield the prediction of greater resistance to extinction for groups receiving tokens during extinction. The effects of varying number of tokens received, and number of conditioning trials were also observed.

METHOD

Apparatus.—The apparatus employed was a portable box designed to have eye-appeal and interest for children 3 to 6 yr. of age. It was placed on a low kindergarten table and the child sat before it on a low chair. The box was painted light green, and on its front was painted the face of a clown. The back of the box opened for easy access to the candy and token reinforcement mechanisms. On the back of the box were mounted three switches by means of which *E* could turn *off* or *on* for each trial, the signal lights, the token reinforcer, and the candy reinforcer. The clown's eyes served as signal lights which lit up at the start of the trials. The nose was a push-button, and both the candy reinforcer and the token reinforcer delivered their contents to the mouth of the clown. A slot for inserting tokens was cut in one ear, and a small box beneath this, on the inside of the apparatus, collected the tokens.

The token and candy dispensers were identical units, differing only in the diameter of the loading tubes. They were designed to release an individual token or candy, respectively, to a slanted plastic slide down which it traveled to the mouth of the clown. The loading tube for tokens permitted the stacking of 200 tokens, that for candy was tall enough to accommodate 35 candies. These tubes were refilled before each experimental session. The tokens used were small poker chips about one-half standard size. There were 50 cut from each of four colors of plastic: red, green, blue, and yellow. These colors appeared randomly. The candy reinforcements were small chocolates with different colored shells, the popular M & M chocolates produced by Marlon and Marlon, New York. They were of fairly standard dimensions, about $\frac{1}{2}$ in. in diameter, and approximately $\frac{1}{4}$ in. thick. They proved to be a highly successful form of candy reward, universally accepted by the children, easily dispensed, small and unmelting in the hand, for short times at least.

Subjects.—The *Ss* were 70 boys and 70 girls between the ages of 3 yr. 5 mo. and 6 yr. 3 mo. Thirty-six children were attending preschool at University Nursery Schools; the rest came from the prekindergarten and kindergarten classes at Edgewood School, Madison, Wisconsin.[3]

Instructions.—No written instructions were read to *S*, but *E* standardized the verbal instructions as much as possible. Each *S* was asked in the classroom if he would like to play a clown game. If *S* said yes, the teacher's permission was obtained to leave the room with *E*. Once in the small testing room *S* was instructed to sit at the small chair in front of the small table holding the box, and *E* would show him how to play the game. The *E* then sat at the side of the small table, facing *S*, and with easy access to the three switches on the back of the box.

The *S* was instructed through the following sequence: observe the signal lights, press the button-nose, receive a token, deliver the token to the slot in the ear, push the button again, receive and eat the candy. This sequence was sufficient to establish the response in all *Ss*. As soon as the eye-lights were illuminated again, *S* pressed the button, and conditioning trials ensued. The *Ss* were told they could eat the candies and in all cases they consumed them at once. The only variations in this technique were for the control groups. Each Group 13 *S* was presented with a box of tokens, and told by *E* that these colored "pennies" were used to work the clown; then attention was called to the eyes as usual, *S* being instructed to insert a token, push the nose, and see what happened. Each Group 14 *S* was told to push the button-nose, insert the token, and push again to see what happened then. When another token appeared,

[3] The author wishes to thank Margery Dawe, Director of the University of Wisconsin Nursery Schools, and Sister Mary Christina, Head of the Prekindergarten and Kindergarten classes at Edgewood School, Madison, Wisconsin for their help in obtaining *Ss*.

TABLE 1

DESIGN OF THE EXPERIMENT

Group	Learning				Extinction (No Candy for All *Ss*)
	Mean Age	No. of Trials	% Tokens	% Candy	
1. 100C-100T-0T	5.025	20	100	100	No token
2. 100C-100T-100T	5.017	20	100	100	Token
3. 100C-50T-0T	5.017	20	50	100	No token
4. 100C-50T-100T	5.008	20	50	100	Token
5. 50C-50T-0T	5.025	20	50	50	No token
6. 50C-50T-100T	5.025	20	50	50	Token
7. 50C-100T-0T	5.025	20	100	50	No token
8. 50C-100T-100T	5.008	20	100	50	Token
9. 100C-100T-0T	5.008	10	100	100	No token
10. 100C-100T-100T	5.008	10	100	100	Token
11. 50C-100T-0T	5.017	10	100	50	No token
12. 50C-100T-100T	5.017	10	100	50	Token
13. Control (No response Required)	5.225	20	Present on table	100	Token
14. Control (No-candy)	5.217			No candy ever	Token

E exclaimed, "*Another* penny!—what do you do now?" When *S* replied that he put it in the ear, *E* answered, "That's right, now do you understand how to play this game? Go ahead." The *Ss* in Group 14 *never* received candy.

Design.—All *Ss* (except Group 14 *Ss*) received one initial trial on the basic-response sequence, in which they observed the signal lights, pressed the nose-button, received a token, delivered it to the slot in the ear, pushed the button again, and received a candy. They were then assigned to the 13 groups of 10 *Ss* each, 5 boys and 5 girls, for the remaining reinforcement and extinction procedures. The groups were equated for mean age and school representation. Table 1 summarizes the design: it identifies each group in terms of its learning and extinction conditions, and shows the mean age of its *Ss*. As may be seen in the table, Groups 1–8 received 20 conditioning trials, with various combinations of 50% and 100% reinforcement by tokens and candy. These eight groups were compared to observe the significance of varying the percentage of the two types of reinforcement independently. Groups 9–12 received 100% token reinforcement for 10 trials, whereas Groups 3–6 received 50% token reinforcement for 20 trials; a comparison of these groups should clarify the effect of differences in percentage reinforcement. If Groups 9–12 are compared with Groups 1, 2, 7, and 8, which received 100% reinforcement for 20 trials, it may be determined whether 20 tokens in conditioning led to more resistance to extinction than did 10 tokens in conditioning.

Each conditioning trial lasted approximately 10 sec. with a 2–3 sec. intertrial interval. Immediately following conditioning, at the start of extinction, *E* turned on the signal lights, and then recorded whether or not a response was made in each 5-sec. unit of time for 40 such arbitrarily defined extinction "trials," or for 200 sec. The six groups receiving the token for button-pushing during extinction and the groups receiving no tokens could be compared with other factors controlled. No groups received candy during extinction. The 5-sec. unit of time was sufficient for the slowest responder to complete one response sequence: press the button, receive a token, insert the token, and press the button a second time. A stop watch was used to time the trials. Each session required approximately 10 min.

Group 13, for which the token dispenser was not used during conditioning, received 100% candy reinforcement during the 20 training trials. During extinction, the supply of tokens was still available, but *Ss* received tokens for pushing the button-nose, and no candy.

Group 14 was used as a control for the secondary reinforcing characteristics of the

tokens. These 10 *Ss* *never* received candy for pressing the button. They did receive tokens, and were instructed to insert each token into the slot before pressing the nose again. They received 40 5-sec. extinction trials in the same fashion as all groups who were extinguished with tokens.

RESULTS

The principal results for Groups 1–8 are shown in Fig. 1, and a summary of the results of an extended trend analysis (Grant, 1956) on the transformed data for these groups is given in Table 2. This test, and all subsequent statistical tests were made on the rational transformation for these data, the arcsin $\sqrt{\text{percentages}}$.[4]

Candy reinforcement.—The 50% candy reinforcement groups show greater resistance to extinction in terms of mean number of responses, than the 100% candy groups, the difference being significant at the .01 level, as seen in Table 2.

Token reinforcement.—In Fig. 1 the extinction data for those groups given 50% token reinforcement during conditioning may be compared to those given 100% token reinforcement. Table 2 reveals that the 50% token reinforcement groups made significantly more responses in extinction. Table 2 also shows that when the eight groups differing in number and percentage of reinforcement, and extinction conditions, are compared, there are significant differences in group slopes, quadratic components, and overall means associated with presence vs. absence of tokens in the extinction condition. It can be seen in Fig. 1 that the four groups given tokens during extinction showed considerable resistance to extinction over the 40 extinction trials, whereas the four groups with no tokens in extinction extinguished relatively rapidly. The groups given tokens in extinction

[4] The author wishes to express her gratitude to the Numerical Analysis Laboratory at the University of Wisconsin for the use of the IBM 650 to calculate these data.

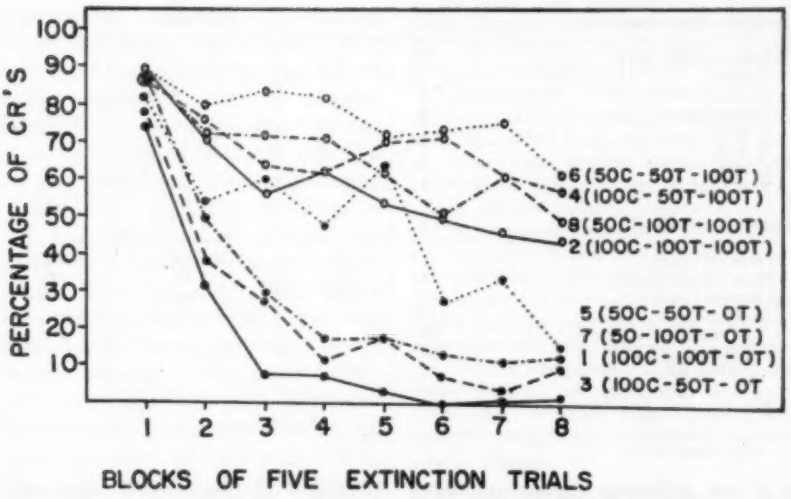

FIG. 1. Percentage of CRs, for successive 5-trial blocks of extinction trials, for the eight experimental groups.

TABLE 2

SUMMARY OF TREND ANALYSIS OF VARIANCE
GROUPS 1–8

Source	*df*	Error Term	*F*	*P*
Between-group means	(7)			
Token	1	(e)	5.28	.05
Candy	1	(e)	29.74	.01
Extinction	1	(e)	202.39	.001
T × C	1	(e)	8.15	.05
T × E	1			
C × E	1	(e)	3.82	
T × C × E	1	(e)	5.58	.05
Between-*S* means (e)	72		(810.239)[a]	
Between-group slopes	(7)			
Token	1			
Candy	1			
Extinction	1	(f)	27.95	.001
T × C	1			
T × E	1			
C × E	1			
T × C × E	1			
Between-*S* slopes (f)	72		(458.379)[a]	
Between-group quadratics	(7)			
Token	1	(g)	4.97	.05
Candy	1	(g)	6.85	.05
Extinction	1	(g)	12.85	.001
T × C	1	(g)	6.01	.05
T × E	1	(g)	1.96	
C × E	1	(g)		
T × C × E	1	(g)	4.88	.05
Between-*S* quadratic (g)	72		(363.560)[a]	
Between-group cubic	(7)			
Token	1			
Candy	1			
Extinction	1			
T × C	1			
T × E	1			
C × E	1			
T × C × E	1			
Between-*S* cubic (h)	72		(437.779)[a]	
Over-all slope	1	(f)	204.54	.001
Over-all quadratic	1	(g)	31.38	.001
Over-all cubic	1	(h)	12.69	.001
Residual	(320)			
Between-group trends	28			
Between-*S* trends	288			
Over-all	4			
Total	639			

[a] Error mean square.

had the shallower curves and gave significantly more responses.

Control conditions.—Comparison of Groups 9–12, given 100% token reinforcement for 10 trials, with Groups 3–6, given 50% token reinforcement

for 20 trials, yielded information on the effect of percentage token reinforcement, with the number of token reinforcements held constant. The 50% token reinforcement groups made significantly ($P < .01$) more responses in extinction. Groups 9–12 were compared also with Groups 1, 2, 7, 8, which received 100% token reinforcement for 20 trials. With percentage token reinforcement held constant, 20 previous token reinforcements did not produce greater resistance to extinction than 10 previous tokens.

A comparison of the transformed data of five groups, the four experimental groups given tokens during extinction, and Control Group 14, given 40 trials with token reinforcement, but *never* receiving candy reinforcement, shows that the No-Candy-Ever control gives significantly ($F = 140.9$, 1 and 350 *df*, $P < .001$) fewer responses than the four experimental groups during extinction. Similarly, a comparison of the responses in extinction of Control Group 13, given 100% candy reinforcement during conditioning, tokens during extinction, and an always-available box of tokens (the response of button-pressing was not required for the tokens for this group during conditioning) with the responses of the two experimental groups also given 100% candy reinforcement during conditioning, and tokens during extinction, shows that the groups who had to press the button to get tokens in conditioning made more extinction responses. The No-Response-Required-for-Token control differs significantly ($F = 92.16$, 1 and 210 *df*, $P < .001$) from the two Response-Required-for-Token groups, with respect to mean number of responses in extinction.

Discussion

The results clearly indicate that tokens can be established as strong secondary reinforcers for preschool children. In addition, partial secondary reinforcement during conditioning is shown to lead to greater resistance to extinction than continuous secondary reinforcement. A comparable result has recently been obtained with rats (Zimmerman, 1957, 1959). Finally, greatest resistance to extinction can be generated by employing partial primary and partial secondary reinforcement procedures simultaneously in conditioning.

A simple discrimination hypothesis for secondary reinforcement has been described elsewhere (Melching, 1954). It is concerned with the absolute differences between conditioning and extinction conditions, and predicts the number of extinction responses in terms of the magnitude of these differences. Melching (1954) conditioned six groups of 10 rats each to press a bar for food. Two groups of rats received a buzzer on half the occasions the bar was pressed. They received food for each bar-press. One group was then extinguished with a buzzer for bar-presses; the other group did not receive the buzzer. These groups correspond to Groups 4 and 3 in this experiment. Two more of Melching's groups were conditioned with food and buzzer for each bar-press and one of these two groups again received buzzers for bar-pressing in extinction. These groups parallel Groups 2 and 1 in the present experiment. The last two groups received food only for bar-presses in conditioning. One group then received buzzer sounds in extinction. Melching found that the presence of the buzzer in extinction did not lead to any greater number of responses. He explained these data by assuming that a change from 50% to 100% reinforcement was equal to a change from 50% to 0% reinforcement.

The simple discrimination model is unconcerned with the direction of differences between conditioning and extinction conditions, and considers, there-

fore, only the absolute differences. It would predict, therefore, no differences in extinction behavior between those groups getting 0% and those getting 100% token reinforcement in extinction, if the groups received 50% token reinforcement in training. This result most decidedly did not occur in the present experiment. Group 4 made significantly more extinction responses than did Group 3, which received the same conditioning treatments but did not receive tokens in extinction. Similarly, Group 6 which received 50% candy and 50% token reinforcement during conditioning, and 100% token reinforcement during extinction, made the greatest number of responses in extinction (309 CRs); in contrast, Group 5, which received the same conditioning conditions, but no tokens in extinction, ranked fifth with respect to number of extinction responses (193 CRs). All groups given tokens in extinction made more responses than their corresponding conditioning groups given no tokens in extinction.

A modification of the discrimination hypothesis applied to describe these data has been described briefly by J. L. Myers (1958). Two factors are considered: the discriminable difference between learning and extinction conditions, and some positive value of the token, resulting from the repeated pairings with the candy during conditioning. This second assumption permits a closer description of the data of this experiment. The model may be expressed in the following form:

$$X = AY + BZ + C$$

where X = total number of extinction responses; Y = the difference between percentage of secondary reinforcement in conditioning and extinction; Z = the difference between percentage of primary reinforcement in conditioning and extinction; A and B are slope constants, and C is the intercept constant.

The total number of responses in extinction for each group was estimated, using the above equation. When A and B were taken equal to 1.0, and C to 295, a reasonable fit was obtained. The model also describes the observed rank-ordering of the eight experimental groups with respect to number of extinction responses, with one slight reversal. It was predicted that the group given 100% candy and token reinforcement in conditioning and 0% token reinforcement in extinction (Group 1) would show the smallest number of extinction responses. Actually, this group gave more conditioned responses (98 CRs) than did Group 3 (63 CRs). The model also predicts the observed main effects, but it predicts zero interactions between the main effects, not the significant interactions observed in Table 2. This result does not necessarily invalidate the model, but rather indicates that it is a first approximation. It is hoped that future research, further refinement in estimation of parameters, and insight into as yet unisolated variables, will yield more exact predictions.

Summary

The experiment was concerned with the extinction of an operant response in children following partial and regular primary and secondary reinforcement procedures. Children were presented individually with a "clown game." When the nose of the clown was pressed, a token was delivered from the clown's mouth. The token was inserted in the ear of the clown, and the nose pressed again. This time a candy fell from the mouth. There were 14 groups of 10 *Ss* each, differing in reinforcement and extinction procedures, and equated for mean age, sex, and school representation. Each child received either 10 or 20 conditioning trials, with either 50% or 100% token reinforcement, and 50% or 100% candy reinforcement, followed by 40 5-sec. extinction trials.

Groups given 50% *candy* reinforcement during conditioning showed greater resistance to extinction than groups given 100% candy reinforcement during conditioning. Groups given 50% *token* reinforcement during conditioning showed greater resistance to extinction than those groups given 100% token reinforcement during conditioning. When the number of token reinforcements was held constant, groups receiving 50% token reinforcement showed greater resistance to extinc-

tion than groups receiving 100% token reinforcement for half the number of trials. Groups given 20 conditioning trials with 100% token reinforcement did not show more resistance to extinction than groups given only 10 conditioning trials with 100% token reinforcement. Groups receiving the token during extinction showed considerably greater resistance to extinction than did groups receiving no token. Furthermore, these token-in-extinction groups differed significantly in the number of responses in extinction from a control group which received tokens for nose-presses, but which had never received candy conditioning.

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INTERSENSORY TRANSFER IN LEARNING SEQUENCES

A. K. P. SINHA AND S. N. SINHA

Institute of Psychological Research and Service, Patna University, India

Experimental investigations of the operation of transfer effects from one sense modality to the other are limited. After reviewing a number of studies relating to interrelations of different sense modalities, Ryan (1940) came to the conclusion that the most fruitful line of research should be the study of intersensory cooperation in normal perception of objects. Worchel's (1951) study of form perception in blind and blindfolded *Ss* showed that transfer was dependent upon the development of both visual and tactual modalities. Semmes, Ghent, and Teuber (1954) conducted an experiment on brain-damaged patients and normal *Ss* and found positive transfer of training from vision to touch and from touch to vision in both the groups, excluding *Ss* having lesions in the parietal region who showed no transfer effect.

Recently, Gaydos (1956) studied the transfer of form discrimination from one modality to the other. The transfer, on the basis of saving scores, was positive for both from vision to touch and from touch to vision. Transfer effects were, however, greater from touch to vision than from vision to touch. The saving scores for trials and errors amounted to 84% and 95%, respectively, when transferring from touch to vision and to 74% and 88%, respectively, when transferring from vision to touch.

The aim of the present experiment was to investigate the operation of transfer in learning sequences from vision to kinesthesis and from kinesthesis to vision.

METHOD

Subjects.—The *Ss* were 40 male postgraduate students of Patna University.

Apparatus.—A linear T maze with 10 choice points and a buzzer attached to it, a finger stylus, and 20 cards (10 of which were blank; the word "Success" was written on the remaining 10) were used.

Experimental design.—The experiment was done under two conditions. In Cond. I, *Ss* were first required to learn Task A visually to a criterion of one errorless trial. This was followed by learning of Task B by kinesthesis to the same criterion. In Cond. II, *Ss* were first required to learn Task B by kinesthesis to one errorless trial. This was followed by learning of Task A visually to the same criterion. Each task consisted of learning a pattern of choices in the sequences and the two tasks had the same number of choices. In order to counterbalance the effects of order of presentation of the tasks in the two conditions, 20 out of 40 *Ss* were first tested in Cond. I in AB order and then in Cond. II in BA order. This order was reversed for the remaining 20 *Ss* so that they were tested first under Cond. II and then under Cond. I. Thus 20 *Ss* were tested in ABBA order and the remaining 20 *Ss* in BAAB, taking the two conditions together. There was an interval of one week between the two conditions.

Instructions.—The *Ss* were given the following instructions in learning by kinesthesis:

> This is a learning experiment. You are required to learn the correct paths of the T maze. You will be blindfolded and a stylus will be put in your right hand. Your hand will then be placed at the first choice point of the maze so that you can move the stylus either to the right or to the left. This you will have to do at all the 10 choice points of the maze. After you have already gone through the entire maze once, the same procedure will be repeated until you have learned to move the stylus to all the correct paths of the maze once in a single trial.

In learning visually, the following instructions were given:

Here are 10 pairs of cards turned upside down on the table before you, one of each pair is placed to your right and the other to your left. In each pair, there is a card on which the word "Success" is written, the other card remaining blank. You are required to point out that card on which "Success" is written. As soon as you do this, the card will be exposed to find out for yourself whether you pointed out the correct card with the word "Success" on it or not. After you have gone through all the 10 pairs once, the same procedure will be repeated until you are able to point out all the correct cards of the entire series once in a single trial.

Control.—Considering that *Ss* might make use of verbal methods in learning both by vision and by kinesthesis, it was thought necessary to devise a technique of controlling the use of such method. But having found no other way of controlling this in a situation of this sort, it was decided to ask each *S* at the end of the experiment to report whether or not he made use of verbal methods in learning the task in either condition. This was considered adequate in that there would be no reason why the *Ss* should give incorrect reports in an experiment of this kind. When the experiment was done, it was found that 37 out of 40 *Ss* reported categorically that they had not made use of verbal methods. The data of the three *Ss* who had reported using verbal methods were subsequently discarded, and data from three other *Ss* were obtained. These three *Ss*, it might be mentioned, also reported categorically that they had not made use of verbal methods.

Results and Discussion

The scores were the number of trials required to reach the criterion of one errorless trial. The means, per cent saving, and t test for each modality are presented in Table 1.

Table 1 shows that the means of trials in learning transfer tasks by visual and kinesthetic modalities were respectively smaller than the means of trials required in learning initial tasks by those modalities. There was a saving of 57.1% in the case of visual modality. In the kinesthetic modality, the saving was 78.6%. It is clear then that positive transfer took place both from vision to kinesthesis and from kinesthesis to vision. The t's between the means of initial task and transfer task for both visual and kinesthetic modalities, are significant beyond the .001 level.

The per cent saving in the kinesthetic modality is greater than that for the visual modality. The difference between the two is significant beyond the .001 level ($t = 11.5$). This shows that the amount of transfer from vision to kinesthesis is significantly greater than the amount of transfer from kinesthesis to vision.

It will be further evident from Table 1 that in learning the initial task by vision the *Ss*, on the average, took fewer trials than in learning it by kinesthesis. Thus it is clear that learning a task by vision is easier than learning a comparable task by kinesthesis. The difference between the

TABLE 1

Means, Per cent Saving, and t Test of Trials for Each Modality

Modality	Trials to Criterion				Saving %	t
	Initial Task		Transfer Task			
	Mean	*SD*	Mean	*SD*		
Visual	47.525	2.490	3.225	1.508	57.1	13.44*
Kinesthetic	13.100	3.007	2.800	1.646	78.6	23.95*

* $P < .001$.

means of the initial scores is significant beyond the .001 level ($t = 13.87$).

The mean performance on the visual transfer task is greater than the mean on the kinesthesis transfer task. This suggests that learning a task by vision preceded by learning a comparable task by kinesthesis is more difficult than learning the task by kinesthesis after learning by vision. The difference between the two means, however, was not significant at the 5% level ($t = 1.71$).

Summary

The study investigated the operation of transfer in learning sequences of choices, from vision to kinesthesis and from kinesthesis to vision. In Cond. I, *Ss* learned the initial task visually and then learned the transfer task by kinesthesis. In Cond. II, *Ss* learned the initial task by kinesthesis and then learned the transfer task visually. The two tasks had the same number of choices in the sequences and in order to counterbalance the effects of order of presentation of the tasks in the two conditions half of the *Ss* were first tested in Cond. I in AB order and then under Cond. II in BA, order and for the other half this order was reversed.

The results obtained were: (*a*) positive transfer took place from both vision to kinesthesis and from kinesthesis to vision; (*b*) transfer effects were greater from vision to kinesthesis than from kinesthesis to vision; (*c*) learning by vision proved easier than learning by kinesthesis.

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WARMTH AND COLD: DYNAMICS OF SENSORY INTENSITY[1]

JOSEPH C. STEVENS AND S. S. STEVENS

Harvard University

The purpose was to learn how the apparent magnitude of warmth and cold depends on the intensity of thermal stimulation. Although it is of interest to know whether warmth and cold obey the same psychophysical law that seems to govern a score of other prothetic continua, an added significance attaches to these thermal sensations for two reasons: (*a*) thermal stimulation of a given area on the skin seems to activate one or the other of two different receptor mechanisms, each having its own dynamic operating characteristic; and (*b*) thermal stimulation provides a striking example of the importance of the "threshold," or the "physiological zero," in the measurement of the stimulus.

The psychophysical law in its general form may be written:

$$\psi = k(\phi - \phi_0)^n \qquad [1]$$

where ψ is apparent, or subjective, intensity, and ϕ is stimulus intensity (e.g., absolute temperature in degrees Kelvin). The term ϕ_0 may be regarded as a device to bring the zero of the physical scale into coincidence with the zero of the subjective scale. Over the range of permissible thermal stimulations, the value of ϕ_0 is a much larger proportion of ϕ than it is for other sensory continua, and the effect of neglecting ϕ_0 is correspondingly more obvious.

With warmth and cold, therefore, an opportunity presents itself to confirm in clear fashion the need for a "threshold correction." The ability of this correction to produce a power function—a straight line in log-log coordinates—has previously been demonstrated for vibration applied to the arm (S. S. Stevens, 1959b) and for the loudness of a 1000-cycle tone (Scharf & J. C. Stevens, in press). The need for an additive constant in the psychophysical power function has also been discussed by Ekman (1958) and Luce (1959). The principle seems to be that the stimulus variable should properly be measured in terms of deviations from the threshold. (Actually, since this added refinement produces a noticeable effect only in the vicinity of the threshold, over most of the range of many psychophysical functions it is a negligible factor).

Given that the magnitude of the thermal stimulus is measured as a deviation above or below the physiological zero, what is the value of the exponent n for warmth and for cold? The results of three different procedures concur in the demonstration that the exponent for warmth (about 1.6) is approximately half again as large as the exponent for cold (about 1.0). Two rather different sensory mechanisms seem to be involved in these thermal reactions.

APPARATUS

The apparatus consisted basically of a number of constant-temperature water baths

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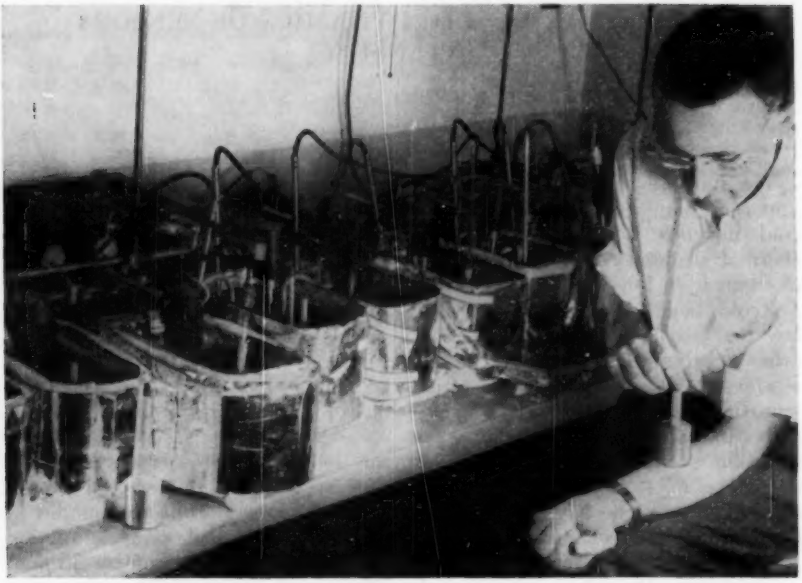

FIG. 1. Showing some of the water baths used for temperature control. The *E* is illustrating how an aluminum stimulator is applied to the inside of the forearm.

(see Fig. 1). By a system of insulated containers, cooling tubes, thermostatically controlled heating units, and stirrers, it was possible to preset the temperature of a bath and to maintain this temperature within a range of 0.1° to 0.2° Celsius. At one end of each bath there was room either for the *O* to immerse his hand, or for the cooling or heating of the metal stimulators that were applied to the *O*'s forearm.

A stimulator consisted of an aluminum cylinder, about 65 mm. in length and 45 mm. in diameter, fastened at one end to a wooden handle. At its other end the cylinder was tapered so that the diameter of the surface applied to the skin measured about 20 mm. Because the mass of the cylinder was fairly large (about 260 gm.), and because the heat capacity of aluminum is high, the loss or gain in temperature during stimulation was small. Measurements with a thermometer embedded in a hole drilled near the surface of the cylinder showed that the temperature changed insignificantly during typical applications of the stimulator.

Little water adhered to the smooth surface of the cylinder upon its removal from a bath, and any moisture that remained could be removed quickly with a cloth. Good thermal contact was achieved by allowing the stimulator to rest of its own weight on the ventromesial surface of the forearm, about midway between the wrist and the elbow.

The temperature of the room varied between about 23.5° and 25.5° C in the course of the experiments. (Unless otherwise specified, temperature will be expressed in degrees on the Celsius scale.)

MAGNITUDE ESTIMATION OF TEMPERATURE ON THE ARM

Procedure

Three separate experiments were run. In the first, a group of 12 *O*s estimated the apparent warmth of six stimuli whose temperatures ranged from 35.0° to 47.2° (95.0° to 117.0° F). The *O* was instructed to let the number "10" stand for the apparent warmth of the first stimulus presented (39.0°) and to assign numbers to subsequent stimuli in proportion to the apparent magnitude of the sensation produced. The stimuli were applied in irregular order for about 3 sec.

each, and approximately 8 sec. elapsed between stimuli. Each stimulus was presented three times.

The second experiment followed a similar procedure for the estimation of apparent cold. Eight *O*s from the previous experiment and five additional *O*s participated. The seven stimuli ranged from 0.5° to 27.7° (32.9° to 81.9° F). The first stimulus, called "10," had a temperature of 21.0°. In this experiment *O* was asked to rub the forearm a couple of times with his hand between stimulus presentations. This procedure seemed to reduce the distracting aftersensations that followed cold stimulation. Each stimulus was presented twice to each *O*.

In the third experiment *O* endeavored to estimate both warmth and cold in a single session. The purpose was to learn whether the difference between the exponents obtained in the first two experiments would hold up when *O* judged a mixed series of warm and cold stimuli. The instructions were, first, to indicate whether the stimulus felt warm or cold, and then to estimate the subjective intensity of the thermal sensation without regard to whether it felt warm or cold, i.e., without regard to the *quality* of the sensation. For one group of *O*s the number "10" was assigned to stand for the apparent intensity of the first stimulus (40.4°), which felt warm. For another group of *O*s the number "10" was assigned to a cold stimulus (22.4°). Each *O* was instructed to assign numbers to subsequent stimuli in proportion to apparent sensory magnitude. By the instructions, *O* was made to understand, for example, that he should assign the number "20" to a stimulus that felt twice as intense (whether cold or warm) as the standard (whether cold or warm). Each of 10 stimuli, ranging from 0.2° to 50.1° (32.4° to 122.2° F), was presented twice in a session. In all, 14 *O*s served, 12 of them in common to both groups. Of these 12, half were given the warm standard (40.4°) in the first session, half the cold standard (22.4°).

The order in which the stimuli were applied was irregular, except that warm and cold stimuli were always alternated.

Results

Subjective warmth.—In Fig. 2 the geometric means of the estimates are plotted, in log-log coordinates, as a function of (*a*) absolute temperature in degrees Kelvin, and (*b*) the difference (in degrees Celsius) between the

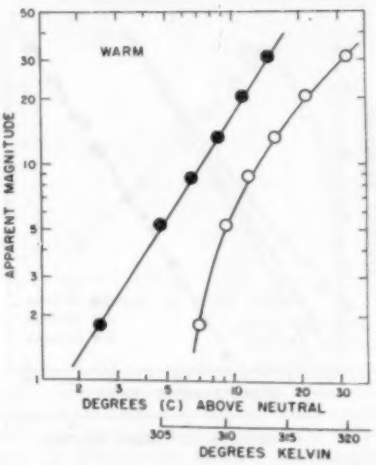

FIG. 2. Magnitude estimation of apparent warmth. Each point stands for the geometric mean of 36 estimates (12 *O*s). The upper abscissa, for the filled points, is a logarithmic scale of the difference in temperature between the stimulus and the assumed physiological zero (32.5°). The lower abscissa, for the unfilled points, is a logarithmic scale of the absolute temperature (Kelvin).

temperature of the stimulus and the temperature of thermal neutrality (so-called physiological zero), which is approximately 32.5° (90.5° F). Plotted against the absolute temperature (Kelvin), the geometric means determine a steep function that is concave downward throughout its length. This curvature in a log-log plot signifies that subjective warmth is not a power function of the ratio scale of absolute temperature. When, however, the same data are plotted against a scale having its origin at the neutral point, the function becomes linear in log-log coordinates. The slope is then about 1.6. Since a neutral point of 32.5° corresponds to 305.7° K, it appears that apparent warmth ψ_w is related to absolute temperature T_K by the formula:

$$\psi_w = k(T_K - 305.7)^{1.6} \qquad [2]$$

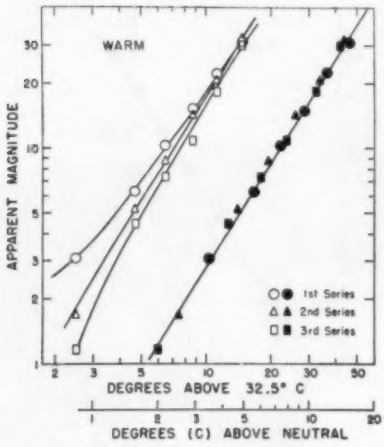

FIG. 3. Magnitude estimation of apparent warmth, showing the effect of three repetitions of a stimulus series. Each point stands for the geometric mean of 12 estimates (12 *O*s). The upper abscissa (for the unfilled points) is the difference between the stimulus and an assumed physiological zero for a given series: for the first series, 31.6°; for the second, 32.5°; and for the third, 33.0°.

The exponent 1.6 implies that subjective warmth is an accelerating function—it grows more and more rapidly—as temperature increases.

The value 32.5°, or 305.7° K, is the assumed average neutral temperature for this particular experiment. It is the value that is required in order for the data to be fitted by a power function. The assumption of a higher neutral point would make the function concave upward; a lower neutral point would make the function concave downward.

Needless to say, the exact neutral point was not measured in these experiments. For one thing it changes with repeated stimulation; for another, it is different for different *O*s. Under ordinary room temperature the average superficial skin temperature of the upper extremities is approximately 32° (89.6° F) (Winslow & Herrington, 1949), but it seems reasonable to suppose that on the average the skin temperature may rise or fall with repeated applications of hot or cold stimuli.

As a matter of fact, this supposition is sometimes confirmed by a systematic change in *O*'s judgments during the progress of the experiment. In the experiment on warmth, a stimulus presented toward the end of a session usually received a smaller estimate than the same stimulus presented near the beginning of a session. This type of adaptation was most noticeable for stimuli close to physiological zero. The nature of this change is brought out in Fig. 3, where the geometric means were plotted separately for the three repetitions of the stimulus series (unfilled points). On the supposition that the neutral temperature was 32.5°, the first presentation of the stimuli determined a function that was concave upward, the second a fairly straight line, and the third a function concave downward. The curvature was changing and the average slope was increasing during the course of the session. These changes are consistent with the hypothesis that the point of thermal indifference moved progressively upward as a result of the skin's being heated.

In Fig. 3 the same data are plotted as filled points on the assumption that the effective neutral temperature increased from 31.6° for the first presentation of the stimulus series, to 32.5° for the second, and to 33.0° for the third. These adjustments of the neutral point cause all 18 geometric means to fall close to a straight line whose slope is 1.6. This outcome suggests that the exponent of the function for subjective warmth may remain invariant under changes in the state of thermal adaptation, but

that a change takes place in the value of the additive constant in Equation 2.

Individual differences in the neutral temperature, variation of the temperature of the room, and a shifting neutral temperature with repeated stimulation are factors that may account for the fact that the variability of the estimates of apparent warmth was perhaps a little greater than that usually encountered with the method of magnitude estimation. The median interquartile range ($\log Q_3 - \log Q_1$) of the estimates of the six stimuli was 0.33. The interquartile ranges for stimuli near threshold were larger than this, and for more intense stimuli, smaller. The larger variability near threshold appears to result from the change in the neutral temperature. Hence the interquartile ranges for the three stimulus series taken separately tended, on the average, to be smaller, especially for the stimuli near threshold.

Subjective cold.—The geometric means of the estimates of subjective cold are shown plotted in two ways in Fig. 4. Plotted against the absolute temperature (Kelvin) the results determine a curvilinear function having a negative slope. The results determine a power function, however, provided the temperature is measured relative to the neutral point. The exponent for cold is then about 1.0, which means that subjective cold grows in direct proportion to the difference between the temperature of the thermal indifference point and the temperature of a cold stimulus. The geometric means of the estimates fit a straight line in log-log coordinates when the temperature of the indifference point is assumed to be about 31.0°. The equation of the straight line in Fig. 4 may therefore be written:

$$\psi_c = k(304.2 - T_K)^{1.0} \qquad [3]$$

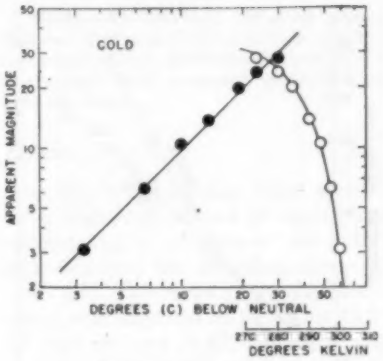

FIG. 4. Magnitude estimation of apparent cold. Each point stands for the geometric mean of 26 estimates (13 *O*s). The upper abscissa is a logarithmic scale of the difference in temperature between the stimulus and the assumed physiological zero (31.0°). The lower abscissa is a logarithmic scale of the absolute temperature (Kelvin).

where ψ_c is subjective cold, T_K is the absolute temperature, and 304.2 is the absolute temperature of thermal neutrality.

As in the experiment on warmth, the neutral temperature seemed to shift in the course of the session. Thus, when plotted relative to a neutral temperature of 31.0°, the estimates for the first presentation of the stimulus series determined a function slightly concave upward, and those for the second presentation determined a function concave downward. As was true for warmth, the variability of the estimates was greater for stimuli in the vicinity of threshold. On the average, however, the estimates of cold tended to be slightly less variable (median $\log Q_3 - \log Q_1 = 0.24$).

Estimates of both warmth and cold.—The results of the third experiment (Fig. 5), in which *O* made estimates of subjective intensity without regard to thermal quality, confirmed the approximate difference in the exponents governing the two power func-

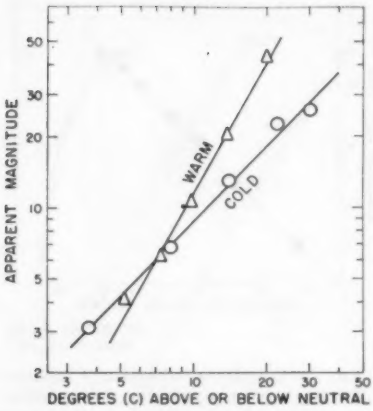

FIG. 5. Magnitude estimation of apparent warmth and cold for a mixed series of warm and cold stimuli. Each point stands for the geometric mean of 52 estimates (13 *O*s). The abscissa is the difference between the stimulus and the assumed physiological zero (31.5°).

tions (Fig. 2 and 4). Although the judgment is fairly difficult, most *O*s felt confident that they could estimate the warm and cold stimuli on a single scale of subjective intensity, and the variability of their estimates roughly equaled the variability in the first two experiments. The two functions obtained with the use of a cold standard (22.4°, called "10") had about the same slopes and the same intercepts as the two functions obtained with the warm standard (40.4°, called "10"). (The near coincidence of the intercepts is largely attributable to the fact that *E* set the temperature of the cold standard to equal the temperature that had received an average estimate of 10 by the first six *O*s, who were given the warm standard). Hence, the two functions in Fig. 5, which are based on the geometric means of all the estimates of each stimulus, tend to preserve the slopes and the positions of the individual functions obtained in the two parts of the experiment. Figure 5 makes it possible, therefore, to compare the relative growth of warmth and cold and, with fair approximation, to locate temperatures of equal apparent magnitude.

Because warm and cold stimuli were presented alternately, the problem of a rising or falling neutral temperature was at least partially avoided. The judgments of both cold and warm stimuli determined fairly good approximations to power functions, provided the average neutral temperature was assumed to be about 31.5°. It may be that the neutral temperature decreased slightly in the course of a session, for the range of the cold stimuli (0.2° to 26.8°) exceeded that of the warm stimuli (35.7° to 50.1°). The slopes of both functions are slightly steeper than those obtained in the first two experiments: about 1.8 for apparent warmth and about 1.1 for apparent cold.

THERMAL SENSATIONS MEASURED WITH A HAND DYNAMOMETER

The method of magnitude estimation presupposes that *O* can assess the magnitudes of sensations by means of numbers. An alternative procedure is to circumvent numerical estimation by allowing the *O* to adjust the intensity of one stimulus to match the apparent intensity of a stimulus delivered to another modality (S. S. Stevens, 1959a). This cross-modality matching makes no explicit demand on a concept of proportionality nor does it presuppose a correct conception of the number continuum. In one set of experiments of this kind (J. C. Stevens, Mack, & S. S. Stevens, 1960), *O* attempted to exert on a precision hand dynamometer a force whose apparent magnitude matched the apparent magnitude of various criterion stimuli. The results for

seven prothetic continua verified the form and slope of the scales obtained by magnitude estimation. The same procedure in the present investigation succeeded in verifying the approximate form and slope of the two scales of thermal magnitude. Instead of being asked to estimate warmth or cold, *O* was asked to assess the subjective magnitude by squeezing the dynamometer.

What *O* does under this instruction is predictable from the scales of apparent thermal intensity and from the outcome of a study by J. C. Stevens and Mack (1959), which showed that the subjective force of handgrip, ψ_f, is related to the physical force exerted, F, by the power function:

$$\psi_f = kF^{1.7} \qquad [4]$$

It follows from the two scales of thermal intensity (Equations 2 and 3) and from Equation 4 that cross-modality matches, obtained by equating ψ_f to ψ_w and ψ_c, should determine two equal-sensation functions of the form:

$$F = (T_K - 305.7)^{(1.6/1.7)} \qquad [5]$$

$$F = (304.2 - T_K)^{(1.0/1.7)} \qquad [6]$$

In log-log coordinates these equations plot as straight lines whose slopes are 0.94 and 0.59. In other words, it is predicted that the slopes of the two equal-sensation functions will stand in approximately the same ratio as do the slopes of the two magnitude functions for warmth and cold.

Procedure

In two separate experiments, the warm and the cold stimuli were applied to the left forearm, and *O* used his right hand to exert the matching force. He was asked to approach his final response by "bracketing," and to signal as precisely as possible the moment at which the matching force was achieved.

Thirteen *Os* matched six warm stimuli (between 35.0° and 47.5°), and 10 *Os* matched seven cold stimuli (between 0.4° and 27.7°). The stimuli were presented twice each, in irregular order.

Results

In Fig. 6 the median force exerted for a match is plotted in log-log coordinates as a function of the difference between the stimulus temperature and the neutral temperature, which was assumed to be about 33.0° for warmth and 31.0° for cold. The straight lines fitted to the medians by the method of least squares have approximately the expected slopes: for warmth, 0.96 (predicted: 0.94), and for cold, 0.60 (predicted: 0.59). Thus it is possible to recover the approximate exponents of the magnitude functions for warmth and cold simply by multiplying the slopes of the equal-sensation functions by the factor 1.7, which is the exponent of the handgrip function.

The forces exerted for a match are about as variable as the magnitude estimates of warmth and cold. Like the estimates, the matches for stimuli

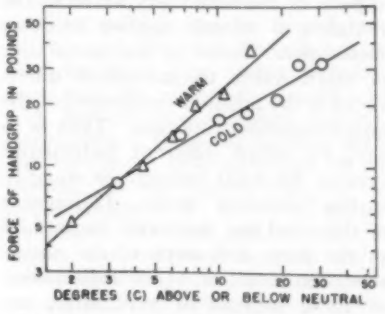

FIG 6. Two equal-sensation functions relating force of handgrip and temperature. *Circles:* the medians of 20 judgments (10 *Os*). *Triangles:* the medians of 26 judgments (13 *Os*). The abscissa is the difference between the stimulus and the assumed physiological zero (for warmth: 33.0°; for cold: 31.0°).

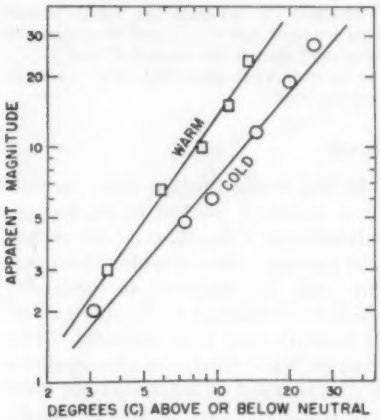

FIG. 7. Magnitude estimation of apparent warmth or cold for hand immersed in water baths. *Squares:* each point stands for the geometric mean of 20 estimates of warmth (10 *Os*). *Circles:* each point stands for the geometric mean of 24 estimates of cold (12 *Os*). The abscissa is the difference between the stimulus and the assumed physiological zero (31.0°).

close to threshold were the more variable. The median interquartile range for the matches ($\log Q_3 - \log Q_1$) turned out to be 0.33 for warmth and 0.26 for cold. These values are typical of the variability found in the matches of stimuli applied to other modalities. Some of the variability is attributable to individual differences in the position (intercept) of the equal-sensation function. That is to say, *Os* adopt different judgmental criteria for what constitutes equality in the "absolute" sense. Differences of this kind are, however, immaterial to the form and slope of the equal-sensation function. (For a discussion of these sources of variability, see J. C. Stevens, Mack, & S. S. Stevens, 1960).

HAND IN WATER

In two additional experiments *O* was stimulated by immersing his hand directly into the water baths. Although the functions obtained with liquid stimulation differed slightly from those obtained with metallic stimulation of the forearm, apparent warmth and cold both approximated power functions, and the exponent governing warmth turned out to be the greater of the two.

Procedure

In one experiment 10 *Os* estimated the apparent warmth of five baths between 34.4° and 44.8°. For about 2 min. before stimulation and for about 10 to 15 sec. between stimulus presentations, *O* kept his hand in an adaptation bath, whose temperature was maintained at about 32.9°. During stimulation *O*'s right hand was immersed to the wrist in a water bath for about 3 sec. In order to prevent his using other cues to identify stimuli (each stimulus was presented twice in a session), *O* was blindfolded, and his hand was guided by *E* from one bath to another. Although this was done as rapidly as possible, the wet hand was unavoidably exposed to the air. The number "10" was assigned to the apparent warmth of the first stimulus, whose temperature was 39.5°. The stimuli were presented in irregular order.

In the other experiment 12 *Os* estimated the apparent cold of six baths between 7.2° and 29.4°. The number "10" was assigned to the apparent magnitude of the first stimulus (18.0°). The temperature of the adaptation bath was 32.0°. In other respects the procedures of the two experiments were the same.

At the end of the preliminary adaptation periods, and between stimuli, the adaptation bath usually felt thermally neutral. The *O* was asked to indicate when adaptation to neutral was complete, and whenever necessary the period of adaptation was extended.

Results

In Fig. 7, the geometric means of the estimates are plotted as a function of the difference between the stimulus temperature and the assumed neutral temperature (31.0°). In log-log coordinates, the points determine two fairly linear functions, whose slopes are about 1.5 (for warmth) and 1.2 (for cold). The effective neutral

temperature was assumed to be a degree or two lower than the temperature of the adaptation bath, because the hand was cooled slightly by evaporation as it passed from one bath to another. This and other difficulties made the use of hand immersion a rather unsatisfactory procedure.

The slope of the function for cold is steeper than that obtained with stimulation of the arm. Whether this difference in slope results from the difference in the method of stimulation, from the uncertain location of the neutral point, or from some other factor is not clear. It may be that the psychophysical functions for warmth and cold depend on such variables as bodily locus, area, and manner of stimulation, but this remains to be determined. Nevertheless, the results obtained with both types of stimulation seem to be consistent with the general psychophysical law expressed by Equation 1.

Discussion

The magnitude functions obtained in these experiments add to the evidence that the power function is the law that describes the growth of apparent magnitude on prothetic continua. In addition, the thermal experiments illustrate especially well an interesting aspect of the dynamics of sensory intensity, for they show clearly that the effective or physiological zero need not be the zero of the physical scale. There is a large difference between zero on the absolute (Kelvin) scale of temperature and the temperature of thermal indifference, which under normal room conditions is about 305° K. Only when the ratio scale of the stimulus is expressed as a distance from the physiological zero does it become evident that apparent warmth and cold grow as power functions, and thus share an important property of prothetic continua in general. What was earlier foreseen as a requirement that the formulas describing sensory intensity should "take account of second-order perturbations in the vicinity of the absolute threshold" (S. S. Stevens, 1957, p. 162) now becomes more explicit.

These findings are given added interest by Luce's (1959) argument that a power function is the only possible function relating two variables, both of which are measured on a ratio scale. Luce suggested further that apparent departures from the power law might be eliminated by subtracting from each stimulus a value equal to the effective threshold, in order to bring the zeros of the physical and the psychological scales into coincidence. The usefulness of this correction principle in extending the generality of the power function has already been demonstrated by S. S. Stevens (1959b) and by Scharf and J. C. Stevens (in press). But the large size of the threshold correction involved in the magnitude functions for warmth and cold makes especially impressive the necessity for measuring the stimulus in terms of its distance from the threshold value. For most other continua the threshold correction is so small that its neglect has little effect, except for very small stimulus values.

The difference in the value of the exponent for warmth and cold implies that the two thermal continua can be distinguished not only by quality, but also by a difference in their operating characteristics. This finding is consonant with the view that warmth and cold involve two different receptor mechanisms. These mechanisms seem also to involve different ranges of response. An aluminum object, for example, cooled to 25° below the physiological zero, feels quite cold but tolerable to the arm, whereas the same object heated to 25° above the physiological zero arouses an almost unbearable sensation of heat.

The magnitude functions obtained in these experiments cannot, of course, be used in the absence of other information to specify the apparent thermal intensity of any object that comes into contact with the skin, for it is obvious that the

apparent temperature of an object is influenced by a complex of properties, including its thermal conductivity, the goodness of thermal contact with the body, and the locus, area, and duration of the stimulation. Furthermore, the uneven distribution of cold and warm "spots" on the body suggests that the operating characteristics for warmth and cold may not be invariant from one part of the body surface to another. The subjective magnitude functions for warmth and cold obtained in these experiments may not represent all types of thermal experience, but they illustrate the fact that the dynamics of thermal intensity can be described by the same power-function law that governs the input-output relation on other prothetic continua.

Summary

The method of magnitude estimation was used to investigate the relation between subjective thermal intensity and the temperature of a stimulus. Two methods of stimulation were used: immersion of the hand in water baths, and the application of aluminum stimulators to the inside of the forearm. Apparent warmth and apparent cold were found to grow as power functions of the difference between the temperature of the "neutral" point and that of the stimulus applied. Thus the growth of thermal sensations can be described by the same power-function law that governs the growth of sensation on prothetic continua in general. On the arm the exponent for warmth is about 1.6, for cold about 1.0.

The difference between the exponents for warmth and cold was verified in two ways. In one experiment *O* estimated the apparent intensity of the sensations produced by stimuli, some of which were warm and some cold. In another experiment *O* exerted on a hand dynamometer a force whose apparent subjective magnitude seemed to match the sensory intensity aroused by the thermal stimulation. The form and slope of the equal-sensation functions generated by the matching procedure are predictable from the magnitude functions obtained by numerical estimation.

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THE EFFECT OF VARIATIONS IN THE FORM OF FEEDBACK ON THE EFFICIENCY OF PROBLEM SOLVING

JOHN W. DONAHOE [1]

University of Kentucky

The present experiments were designed to study problem-solving behavior as a function of the manner in which information regarding prior performance was fed back to *S*. A geometrical game was employed as the task.

EXPERIMENT I

Method

Subjects.—For the initial experiment, 24 *Ss* were selected from the laboratory sections of introductory psychology. The work was required as part of the course.

Procedure.—By means of a random procedure, the 24 *Ss* were assigned to two subgroups of 12 *Ss*. All *Ss* were given a *map* of the ocean. This map consisted of a piece of white cardboard on which was drawn a 7×7 grid with the grid lines spaced 1 in. apart. The maps ranged from A to G in latitude and from 1 to 7 in longitude. Of the 49 intersections, 12 were distinctly marked with a large black dot. The *Ss* were told that the dots corresponded to the possible locations of enemy ships. The primary purpose of Exp. I was to study differences in performance as a function of the form of information presentation irrespective of the latitude-longitude correlation. Accordingly, 12 pairs of maps were constructed with the dot positions independently and randomly determined for each. One map of each pair was assigned to a subgroup.

The *S* was then shown the *fire control panel*. On this panel were located 12 lever action switches corresponding to the 12 possible ship locations represented on the map. Depending upon the experimental condition to which *S* had been assigned, either one or two pairs of lights were located above the switches. In any case, one of each pair of lights were marked *nearer*, while the other was marked *farther*.

Each *S* given information from a single pair of lights was instructed to fire (by raising a switch) until he hit the enemy ship, but to choose wisely in order to sink the enemy with as few shots as possible. After a shot was made, the fire control panel signaled whether the present guess was *nearer*, *farther*, or the *same* distance away from the enemy ship as the previous shot. The signal, *same*, was represented by the condition in which neither light of the pair was illuminated. All replies were based upon the Euclidean distance between the relevant positions in two-dimensional space. This method is known as the *combined* condition since both latitude and longitude were considered together in the reply.

In the condition in which two pairs of lights were present, the instructions were similar with one exception. Here, the machine gave two signals after each guess, one signal with respect to latitude (letters), and one with respect to longitude (numbers). As *S* was told about each dimension separately, this method of presenting information was known as the *separate* condition. Half of the *Ss* served under the separate condition (two sources of information) and half under the combined condition (one source of information). In both conditions, *Ss* were allowed to proceed at their own pace and to take notes if they desired. Also, the meaning of the three possible machine signals was clarified with illustrations from the maps.

All *Ss* played 10 games, a game being completed when the target ship was sunk. The onset of a buzzer and a light signified this event. The location of the ship was randomly determined for each game. The number of guesses required to sink the enemy was recorded as the criterion variable.

Apparatus.[2]—Each of the 12 switches on the fire control panel introduced a predetermined resistance between the grid and ground of an electronic bridge circuit. The magni-

[1] This article is based upon a dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at the University of Kentucky.

[2] The author is indebted to Ralph Albers for suggesting the circuit used in the apparatus.

tude of resistance was proportional to distance in the map. One control grid of a dual triode tube was biased in accord with the resistance placed between it and ground by *S*'s previous guess, while the bias on the other grid reflected the present guess. A single-pole, double-throw polarized relay was put in one arm of the bridge. If the negative bias of the grid associated with the previous guess was greater than that of the grid associated with the present guess, the relay turned on a light which indicated that *S* was nearer. If the reverse was true, *S* was farther. Finally, in the case where the grid had equal negative bias, the relay remained in the null position and no light went on, indicating that *S* was the same distance away from the target as on the previous guess. Two such bridge circuits were built. One served in the combined information condition and also represented latitude in the separate condition. The other was used only in the separate condition where it represented longitude. The resistance associated with each switch was governed by a rotary switch on the back of the panel. By this technique, an entire game could be played with one setting of the rotary switches.

Results

An analysis of variance was used to evaluate the guessing data. Because it was possible for the target to be discovered on the first guess 1 time in 12 by chance alone, the 10 games per *S* were grouped into blocks of 2 games in order to secure a more representative estimate of variability. As there were no *S*s treated alike, the pooled Maps interactions were used as error variance.[3]

Although it can be shown, using a locus principle, that the separate method always leads to a logical elimination of at least as many positions as does the combined method, *S*s in the separate condition did not require significantly fewer guesses to attain the target ship. In fact, the prediction verged on significant *reversal* ($F = 4.31$; $1/11$ df; $P < .10$). The mean number of guesses for *S*s in the separate method was 7.1, while that for the combined condition was 4.0. Furthermore, no reduction in the number of guesses occurred as a function of games.

An empirical check on the informational superiority of the separate condition was obtained by tallying the number of points logically eliminated by the first guess for each game. On the average, 7 positions were eliminated under the combined condition as opposed to 9 positions under the separate method. Thus, for some reason, *S*s were unable to use to full advantage the information as fed back to them from two sources. Only the variance associated with the maps variable was significantly different from error ($F = 2.92$; $11/11$ df; $P < .05$) in the analysis of the guessing data. One interpretation of this finding is that the latitude-longitude correlation, which was allowed to vary randomly, was critical in determining the ability of *S*s to assimilate the information. Experiment II was directed to this point.

Experiment II

Method

Subjects.—Thirty-six *S*s were used in Exp. II. Again, they were recruited from the laboratory sections of the introductory psychology course.

Procedure.—The original 36 *S*s were randomly subdivided into three groups of 12 *S*s each. The map for Group 1 possessed a .00 latitude-longitude correlation, and hence, a low redundancy between sources of information in the separate condition. Groups 2 and 3 were characterized by maps with .86 and

[3] The summary tables for all analyses of variance have been deposited as Document Number 6377 with the ADI Auxiliary Publications Project, Photoduplication Service, Library of Congress, Washington 25, D. C. A copy may be secured by citing the document number and by remitting $1.25 for photoprints, or $1.25 for 35-mm. microfilm. Advance payment is required. Make checks or money orders payable to: Chief, Photoduplication Service, Library of Congress.

1.00 correlations, respectively. Thus, for Group 3, the amount of information imparted by the combined and separate conditions was exactly the same (one source completely redundant). One half of each of the redundancy groups was given information by the combined method, one half by the separate method.

Groups 2 and 3 were further partitioned into two equal subgroups, one of which was given a positive and the other a negative longitude-latitude correlation. Within each correlation-sign combination were three randomly selected sets of 10 target locations. The instructions used were the same as in Exp. I. However, in Exp. II the maps varied from A to L in latitude and from 1 to 12 in longitude in order that a correlation of 1.00 might be represented. All *S*s were given 10 games, and the number of guesses and the amount of time required to discover the target were recorded.

Results

Number of guesses.—Two analyses of variance were performed, one for the .00 correlation group and one, for the .86 and 1.00 groups. This was necessitated by the absence of the sign variable in the .00 group. In the first analysis conventional error terms were possible due to the presence of more than one *S* per group. For the second analysis, target interactions (pooled where homogeneous) were used as error.

With the .00 map, the method of presenting information to *S*s was not a significant source of variance. However, once again, numerically fewer guesses were required by *S*s under the combined condition (see Table 1). The number of guesses to target attainment decreased significantly ($F = 3.87$; $4/24$ *df*; $P < .025$) from 5.4 to 3.1 guesses.

The analysis of the data obtained under .86 and 1.00 correlations revealed a significant interaction ($F = 5.75$; $1/12$ *df*; $P < .05$) between the map correlation and the method of information presentation. Two

TABLE 1

NUMBER OF GUESSES AND RATE OF RESPONDING AS A FUNCTION OF SOURCES AND LATITUDE-LONGITUDE CORRELATION

Latitude-Longitude Correlation	Mean Guesses		Mean Rate (Sec.)	
	1 Source	2 Sources	1 Source	2 Sources
.00	4.2	4.7	24	33
.86	4.6	3.5	22	35
1.00	3.6	4.2	23	15

sources of information were inferior to one source with a 1.00 latitude-longitude correlation, but superior with a .86 correlation (see Table 1). The sign of the correlation also was a significant factor in determining the effect of the method of presenting information ($F = 4.81$; $1/12$ *df*; $P < .05$). An inspection of the appropriate means revealed that a positive correlation led to the fewest number of guesses with a 1.00 map (3.6 vs. 4.1 guesses), while a negative correlation was most beneficial with a .86 map (3.6 vs. 4.5 guesses). Unlike the .00 correlation, a significant decrease in the number of guesses did *not* occur as a function of trials.

Rate of guessing.—The interval between the first guess and the attainment of the target was recorded. This time was divided by the number of guesses in the game and evaluated by two analyses of variance analogous to those used to appraise the guessing data.

The rate of responding increased in all three map correlations. In the 1.00 map, the rate increased over the five blocks of games from 24 to 15 sec. ($F = 6.06$; $4/24$ *df*; $P < .01$). The average time per guess fell from 36 to 26 sec. in the .86 map and from 34 to 27 sec. in the .00 map ($F = 2.94$; $4/64$ *df*; $P < .05$). Generally, responding was slower under the sepa-

TABLE 2

ANALYSIS OF THE DEPENDENCIES BETWEEN RESPONSES

Source	*df*	*F*
Between *Ss*	17	
Correlation (C)	2	1.21
Between *Ss*, same group	15	(150.07)
Within *Ss*	90	
Order of dependency (D)	2	85.44**
Measures (M)	1	199.83**
D × M	2	3.50*
D × C	4	1.64
M × C	2	1.88
D × M × C	4	.06
Pooled *Ss* interactions	75	(54.61)
Total	107	

* $P < .05$.
** $P < .01$.

rate method (see Table 1). However, there was a significant interaction with map correlation ($F = 4.89$; 1/14 *df*; $P < .05$), the highest rate occurring with the 1.00 map and two sources of information. The rate of responding with one source of information was relatively invariant over the correlations sampled.

Dependencies between guesses.—In order to examine the sequential relationships between responses more closely, the games were simulated on an IBM 650 digital computer.[4] The *Ss*' guesses were read into the computer and the number of points logically eliminated by each guess was determined. (Only the data from the combined condition were analyzed in this manner due to limitations imposed by the computer. Thus, the following results are probably overly generous estimates of *Ss*' information processing ability.) The data were tallied in three ways: (*a*) for each guess singly, (*b*) in conjunction with the immediately preceding guess, and (*c*) in conjunction with the immediately preceding two guesses. There was a significant gain in the amount of information presented in these three combinations. The respective values were 6.6, 8.6, and 9.9 points. There were no differences between the correlation groups with regard to this measure.

To estimate the *goodness* of a guess, where a good guess is defined as guessing a position which has not been logically eliminated on the first; first and second; or first, second, and third guesses preceding the one under consideration, the following comparisons were made. The average number of points remaining after a guess was divided by 11 (*S* could not choose the same point on successive guesses) to secure an estimate of the probability of making a good guess by chance alone. This was the expected proportion of good guesses. The obtained proportion was arrived at by dividing the number of good guesses by the total number of guesses of the type under concern (first, second, or third order of dependency). In this manner, three expected and three obtained proportions were secured for each *S*. The analysis of these values (neglecting the sign

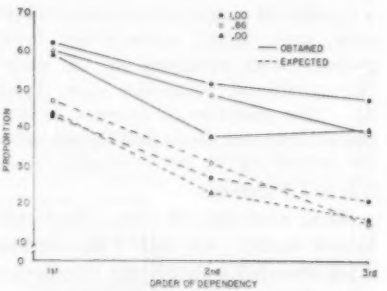

FIG. 1. The proportion of obtained and expected *good* guesses as a function of the order of response dependency.

[4] The author is indebted to the Computing Center of the University of Kentucky and especially to J. W. Hamblen for assistance in the following analyses.

variable in the .86 and 1.00 maps) is presented in Table 2. As shown in Fig. 1, *Ss* performed at better than chance expectancy unaffected by the map correlation. There was a significant decrease in the proportion of good guesses as a function of the order of dependency indicating a retention loss. However, this drop was not as sharp as that indicated by the expected values (D × M significant).

Discussion

As the average amount of information per guess (number of points logically eliminated) was greater with two sources than with one source, it was expected that the number of guesses required to attain the target would be less in the former condition. Generally, this expectation was not upheld. Inferior performance with two sources of information was demonstrated with random correlation maps and with .00 and 1.00 maps. Only in the case of a .86 latitude-longitude correlation was the prediction upheld. It would appear that the ability to combine informational outputs was, in this task at least, contingent upon a moderate degree of redundancy between sources. Some precedent for this finding is provided by an eight-cue, probability learning study conducted by Calvin and Curtin (1958). Two of the eight cues were relevant to the two-choice response required of *S*. With uncorrelated relevant cues, all *Ss* were found to use only one of the two cues to a significant degree although some *Ss* were given over 2,000 trials. In the map game, however, the difficulty presented by the .00 map was largely surmounted as the number of guesses per game decreased with continued play.

Not only did the magnitude of the latitude-longitude correlation significantly affect performance, but also its sign. Further inquiry into the role of this variable is needed as the present results may be an artifact of the unequal strengths of associative connections between certain numbers and letters (A with 1, B with 2, etc.).

For all but the 1.00 correlation, the rate of guessing was highest with one source of information. Nevertheless, the slower rate with two sources in the .00 map condition did not lead to fewer guesses. The trend toward more rapid responding where one source of information was completely redundant (the 1.00 map) may have its counterpart in a visual discrimination study reported by Eriksen (1954). He found 4.1 bits transmitted per stimulus when the stimuli varied simultaneously in size, brightness, and hue; whereas, variation in any of these attributes singly resulted in the transmission of only 2.7 bits. This was in spite of the fact that the attributes were perfectly correlated (i.e., two were completely redundant).

Under what was the most favorable method of presenting information (one source), the proportion of good guesses was .60 with respect to the information afforded by the immediately preceding guess. This value dropped to .50 and .42 for the second- and third-order dependencies, respectively. A clue to the mechanisms underlying this borderline performance can perhaps be supplied by *Ss'* spontaneous comments during the games. Rather than regarding the signals *nearer* and *farther* as objective methods of providing information, these stimuli apparently acquired differential reinforcing properties. This was particularly evident when the fire control panel signaled *farther*. Many *Ss* retraced their steps after this reply, a strategy which, needless to say, resulted in no new information but did insure the occurrence of *nearer*.

Summary

Subjects played a two-dimensional geometric game under two conditions of feedback concerning the consequences of their responses. One group was informed about a response from a single source which collapsed the two-dimensional character of the game by means of Euclidean distance measures. A second group received information from two sources which separately reflected each

dimension of the game. Despite the greater amount of information available per response in the latter condition, performance, as measured by the number of steps required to complete the game, was inferior. Only in the case of a moderate degree of redundancy between the two sources did relative amount of information and performance covary as expected. This was accompanied, however, by a decrease in the rate of responding.

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ERRATUM

In the article "Role of Postural Experiences in Proprioceptive Perceptions of Verticality" by Richard G. Pearson and George T. Hauty (*J. exp. Psychol.*, 1960, **59**, 425–428) Figures 1 and 2 should be reversed.

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